Progress of Mechanical Equipment, Process Control and Instrumentation Technologies for Innovation in Steel Production Processes*


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Synopsis:

Steel business has encountered very rapid and drastic changes in economical circumstances for the last decade and Kawasaki Steel has continuously developed mechanical equipment, process control and instrumentation technologies by applying various kinds of fundamental researches and taking into account customer's requirements. These technologies constitute the most important technological elements in steel production process and include the following 3 fields: (1) Design and construction of commercial production process based on fundamental basic research results, (2) Improvement in production process based on the analysis of phenomena, and (3) Increase in the productivity of existing plant through equipment administration. This paper reviews the technical development of Kawasaki Steel in the above-mentioned fields during the last decade, and introduces some technical topics, e.g., "Ultra-short term revamping of Chiba Works No. 6 blast furnace", "High quality cast products in steelmaking and continuous casting process", "Continuous hot strip production", and "Optimal control for hot strip finishing mill". The perspective of steel production process in the future is also described.

1 Introduction

The steel industry is a typical process industry and the history of expansion of a process industry is also a history of progress in processes. The progress in processes has been made by virtue of technical advancement through cooperation of many providers of technologies and at the same time, it is a result of the fusion of various elements of the steel industry itself including product development techniques, operation know-how and equipment technology.

Throughout the process of technological progress in these 50 years, efficient and continuous production of uniform and high quality products was pursued in the steel production processes. The progress in process technologies has materialized the construction of equipment that is endurable in very severe environments and has played important roles in the changes in steel manufacturing in various aspects including operation of large and complicated systems and establishment of technologies to control quality to a high accuracy.

The untiring technological development will further continue toward the progress of steel production technology and achievement of highly efficient productivity. Under the circumstances, advancement in process technology made in Kawasaki Steel in the last ten years is reviewed and the technical development in each field of production is described in this paper.

2 Changes in Process Technology

2.1 Process Technology and Its Functions

The process technology has the function of setting various unique problems in steel production processes including ironmaking, steelmaking and rolling on the

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basis of basic engineering knowledge in various fields of engineering such as mechanical engineering, electrotechnics and instrumentation, systems engineering and chemical engineering. The following three points summarize the major functions of process technology.

(1) Process Development and System Construction
To materialize the fundamental theory of production obtained through product development and production process development in actual production systems

(2) Improvement of Processes
To plan the improvement of the productivity, reliability and accuracy of existing production processes

(3) Improvement of Maintenance and Systems
While planning to strengthen and to extend the life of individual pieces of equipment and parts, to plan the improvement of the reliability of systems

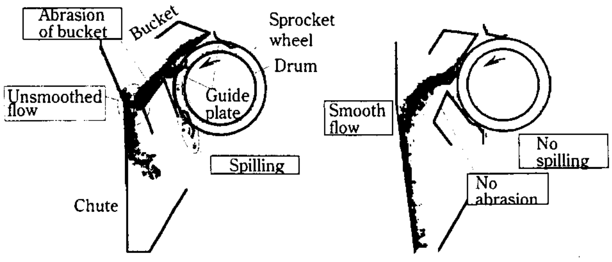
The ideas existing at the roots of the respective functions are engineering elucidation or inference and quantification of various phenomena which arise in production processes and systems. It is not an exaggeration to say that progress in process technology depends on the accumulation of analysis and modeling of phenomena. Through elucidation of these phenomena, it has been planned to improve the accuracy of the technical specifications which are to be introduced and the essential direction of technological development has been made clear, thus the efficiency of development has also been improved very much.

The need for highly accurate control based on clarification of various phenomena have created many different sensing and control techniques and the need for significant improvement of the reliability of systems has stimulated development toward further improvement of reliability of general mechanical element apparatus which are considered to have been already established and the results of such developments have opened the road to using these apparatus in other industries. In the stage of carrying out construction and modification of systems, various unique construction methods have also been created for assurance of quickness, safety, reliability, etc.

2.2 Changes in Process Technology at Kawasaki Steel

2.2.1 Ironmaking field

The most important objective in the field of ironmaking is to steadily supply low cost molten iron while trying to reduce the huge energy consumption and to recover generated energy. The equipment operates under severe conditions such as high temperature, high pressure and abrasion. Important subjects under these conditions are such matters as prolonging equipment life which is the basis for steady supply of molten iron and to minimize the required working period for revamping of blast furnaces and repair of equipment for the pur-



(a) Conventional layout (b) Improved layout

Fig. 1 DEM simulation for discharging behavior of bucket elevator

pose of reducing economic losses due to suspension of the system's operation.

As examples of prolonging equipment life, the No. 6 blast furnace of Chiba Works has achieved a world-record long life of 20 years and 9 months and the No. 2 blast furnace of Mizushima Works is now extending that world record. For extension of the life of these furnaces, various areas of equipment technologies are making contributions. These areas include cooling plates and staves combined composition with the brick supporting function being strengthened[1], design for blast furnace body based on structural analysis with also the last stage conditions being taken into consideration, high reliability stave structures, blast furnace maintenance technology including staves diagnosis and maintenance and high accuracy hearth erosion profile estimation techniques[2] using the boundary element method. For coke ovens with a view to having a life of more than 50 years, the company developed a drastic brick renewal method.

Some typical results of shortening construction periods are the repair of the No. 6 blast furnace of Chiba Works in 62 days using the large block ring construction method[3] detailed in the next chapter and the firebrick resetting work for a coke oven in 14 days by making firebricks in large blocks and by using the quick heating technique. The company achieved the world's shortest construction periods, less than half the conventional times in both cases.

As for energy savings, an original emergency shut down system for protection of the equipment and a mist cooling system were developed for BDC (blast furnace gas dry cleaning system) and the highest class operation rate of 95% has been continuously maintained. Furthermore, the company developed a control system using fuzzy logic and the thermal efficiency of the hot stove combustion gas was improved by 3%.

As a countermeasure against wear by coal, ore, etc., the company developed a high accuracy lumpish body simulator which uses the dispersion element method (DEM)[4] and as a result, steady operation of the raw material handling system was made possible. **Figure 1** shows an example of the improvement made for continuous unloaders. This simulation method has also been applied to development of the ore charging device for sintering machine and to estimation of shape and distribution of blast furnace changing materials and has been a powerful tool for using low-cost raw materials.

2.2.2 Steelmaking field

The major objective in the field of steelmaking is to achieve inexpensive mass supply of high grade slab. For this objective, the company worked hard to improve the process of agitation steelmaking for high purity steel and to improve the production process for defect free casting.

As for agitation steelmaking the company developed a number of quantitative analysis models and thus used these models for combined blowing converters which were expended taking the opportunity of introduction of Q-BOP in the Chiba Works, as well as for hot metal pretreatment, etc. As a result, stabilization of the process and equipment life extension were realized. The models that were developed include a model to accurately estimate the gas quantity blown into molten steel and iron taking thermal expansion of the gas into consideration, a model to estimate the temperature around tuyeres for extension of tuyeres' life, a model to predict vibration of a converter's body when blowing in the gas, taking various factors even including the arrangement of the tuyeres into consideration and a gas carrying model for power[5]. Furthermore, with respect to the RH degassing treatment, the need for steady mass production of extremely low carbon steel with a carbon content of less than 15 ppm has been met by shaping the lower vessel into an ellipsoid and using a model to estimate the decarburization speed from the exhaust gas velocity[6].

As for casting technology, there are two techniques. The first is to solidify poured molten steel without any defect of various kinds such as cracks, inclusions, bubbles and center segregation and the second is to pour into mold without contamination. For the former, a number of models were developed including those for solidification progress, flow model of unsolidificating pool and estimation model of stress and strain at the solidified part. The technique developed is to quantitatively estimate the number of generated defects of various kinds by comparing the results of estimation by models with the actual phenomena and to suppress generation of defects based on that estimation. With respect to the latter, the company developed the tundish nonoxidation heating method (N_2 gas jet burner)[7] which uses high temperature N_2 gas. The method is illustrated in **Fig. 2** and reoxidation of molten steel is now prevented.

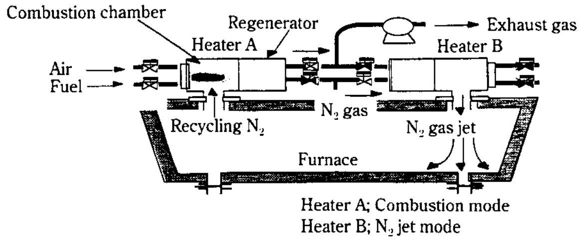


Fig. 2 Tundish equipped with a N_2 jet heater

2.2.3 Hot rolling and plate rolling field

In the field of hot rolling and plate rolling field, the company worked to manufacture steel plates or sheets of high quality, particularly in size accuracy and mechanical properties, as well as to develop technologies toward the need for high productivity. Furthermore, the company combined various automatic control techniques and enhanced these techniques to the endless rolling technology applied in the No. 3 hot strip mill of Chiba Works.

For improvement of the accuracy of plate and sheet dimensions, the company made three-dimensional rolling simulation technology represented by the rigid-plastic finite element method available for practical use for the first time in the industry and constructed the basic model for the rolling method. Utilizing this model, the effects of various factors on plate thickness, plate crown, edge drop, etc. were quantified and the phenomenon of deformation in width direction was clarified.[8] Furthermore, in order to maintain excellent controllability against various kinds of external disturbances in actual rolling, the company made the optimal regulator control[9] and preview control practically usable. These methods of control are taking into consideration complicated mutual interference of various factors in finishing rolling such as reduction, tension and material speed. An asymmetrical rolling control technique has also been established. This technique was designed taking the sheet threadability including meandering into consideration. On the other hand, the control standard was made clear by quantifying the effects of mechanical accuracy on the sheet threadability[10], etc. and at the same time, the mechanism of work roll keeper and the mechanism of work roll shift[11] were improved.

With respect to heating and cooling which strongly effect the determination of the materials' quality, a model which accurately estimates the temperature changes of plates in the heating furnace from the inlet to the outlet was developed, and this model has been used for determination of operating conditions and modification specifications of the furnace when manufacturing new products. In addition, in order to actualize production of TMCP (thermomechanical controlled processing) steel, a uniform strong cooling technique 1.7 times faster than the conventional method was developed.

By developing new equipment such as a sizing press which makes efficient big reduction possible by reducing the difference in balance between rolling and continuous casting, the productivity has been improved.

Furthermore, for the necessities to improve the accuracy of plate dimensions and to clarify various phenom-

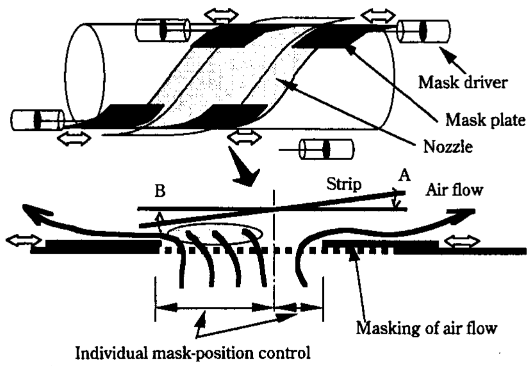


Fig. 3 Helical turner and pressure distribution control system

ena, the company developed tough and highly reliable sensors which enable measurement of plate thickness, crown, etc. even in poor environments due to water, heat and vibration in the immediate vicinity of and inside mills.

2.2.4 Cold rolling and coating fields

In the fields of cold rolling and coating, the company has been carrying forward technological development for meeting the growing needs for highly functional steel sheets with high durability, high formability, etc. such as for automobile or can use. Technological development has also been carried out to improve productivity and quality. With respect to improving productivity, defective points found during high speed carrying of strips such as seizure and chattering were prevented through development of various techniques including rolling lubrication, bearing lubrication and use of AC variable speed motors and the world's highest speed of 2 800 m/mm was realized at the No. 2 TCM of Chiba Works. Furthermore, techniques to prevent strip buckling and wandering were established and high speed stable operation at 1 000 m/mm was achieved at the No. 4 CAL of Chiba Works.

In relation to prevention of surface defects, as a method to change the pass-line advancing direction in a plane in a contact-less manner, the floating helical turner system[12] shown in **Fig. 3** was brought into use for the first time in the world and operation of the No. 2 CAL of Chiba Works and a skin-pass mill in series was actualized.

As for CGL, technological development was carried out mainly on zinc pots and pot equipment which are important kinds of equipment for securing quality galvanization. By water model experimentation and numerical analyses, the technique to control flow inside of the pot was established for prevention of dross adhesion defect (adhesion of minute foreign materials in Zn pots). In addition, equalization of coating thickness was achieved by means of the width direction plate warping prevention technique and the coating weight control

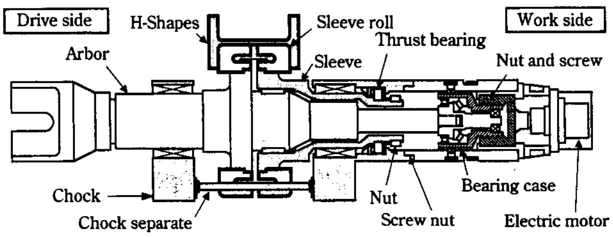


Fig. 4 Schematic of adjustable width rolls

technique[13] based on the gas flow theory. By integrating these techniques, the pot equipment of Mizushima Works were refreshed making a contribution to stabilization of quality and improvement of productivity.

As for EGL, the world's first metallic Ni dissolving method was developed as a technique to supply Ni-ions to Zn-Ni galvanization liquids. Furthermore,the coating phenomenon when using roll coating was studied with its model made by applying the elast-hydrodynamic lubrication theory[14] and uniform coating was made possible also for various different coating specifications

2.2.5 Steel bar shape

In the field of steel bar shape, for the purpose of responding to the needs for commercialization of high accuracy fixed outer dimension H-breams for architectural use and for expansion of size repertoires of these products the company tackled development of various sizing techniques rolling and cross section temperature control techniques with the major points put on development of equipment and sensors.

Multi-size rolling was actualized by the development of on-line adjustable width rolls[15] illustrated in **Fig. 4**, roller straightner and on-line correction equipment of flange out-of-square for H-shapes and these developments contributed to the 1989 commercialization of fixed outer dimension H-shapes. Furthermore, for improvement of size accuracy, the company developed and brought into use hot sensors[16] able to measure three-dimensional section size and shape.

On the other hand, with respect to section temperature control, a test apparatus capable of simulating hot conditions was designed and the specifications and structure of accelerated water cooling of flange were determined.

Also for the bars and rods steel manufacturing process, the company tackled classification of the rolling phenomenon of 4-roll mills designed to respond to the needs for improvement of accuracy and expansion of size repertoires and developed a rigid-plastic FEM analysis model[17] capable of clarifying various phenomena in three-dimensional rolling. These efforts have made it possible to quantitatively estimate the characteristics of rolling torque and load, characteristics of width spread as well as the cause of critical condition for sppressing grain coarsening of the mill and have contributed to actualization of stable rolling operation.

Table 1 Development of equipment management technology

1980~	1990~	2000~
Standardization	Reliability technology	Extension and concentration of managing subjects
Management system Diagnosis system	Advanced diagnosis technology	Managing/diagnosis system down-sizing
	Device life prolongation Device quick change	Mechanical element toughening

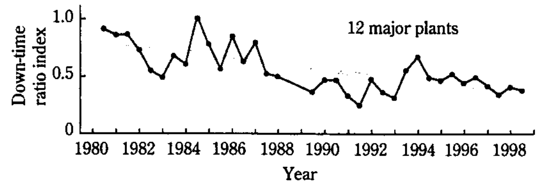


Fig. 5 Trend and down-time ratio (mechanical equipment)

2.3 Equipment Management Technology

In steel works where a huge group of various equipment must be well managed, and an enormous number of data bases and various management systems were constructed in the 1980's as shown in **Table 1**. The data bases related to maintenance cover the standardization for maintenance of individual control items, design and purchase of equipment, etc. and the management systems include those for equipment management and equipment diagnosis. With such a background, the basic picture of the present equipment management was established. It is efficient management of equipment with a small number of personnel.

Successively from the mid-1990's, setting the primary object on operation of equipment at maximum capacity with the lowest possible maintenance cost, various activities have been started and are presently in progress including life extension of equipment, reduction of the number of maintenance items by improvement of working efficiency and cycle extension and reduced time for planned suspension of operation. These activities involve finely harmonizing various individual techniques and various management diagnosis techniques. Some examples of individual techniques are the design of optimal structures and development of optimal materials which are suitable to the operating environment of the equipment[18] and development of original tools and working processes. The examples of management diagnosis techniques are the maintenance planning method based on reliability engineering[19] for management of a large number of pieces of equipment and the life estimation technique by application of fracture dynamics. Furthermore, with the methods of equipment management being upgraded, the company constructed a maintenance support system[20] which allows retrieval of drawing and trouble information by electronically processing such information. For control systems which require great skill in trouble shooting, in particular, the company developed a expert system of failure inference[21] and made a great contribution to improving business efficiency and reducing troubles.

From the later half of the 1990's, the company expanded the equipment management system and it was made possible to timely carry out equipment improvement activities. Namely, for a huge number of pieces of equipment, exceeding 4 700 000 per steel work, it was made possible to qualitatively grasp the condition of equipment for each individual unit according to the changes in the operation and to the degree of deterioration due to aging. Making use of such systematic equipment management techniques and through continuous improvement of equipment, the number of equipment troubles was reduced to about one half over the last 10 years as shown in **Fig. 5**. In this period, the company achieved development of various technologies such as a low speed bearing diagnosis technology and a mechanical accuracy evaluation technology for rolling equipment using impact load models.

In recent years, however, the limits in technological development if individual systems are improved just through the introduction of the manufactures' technologies so far available have been foreseen and the company is now extending its activities to its own research and development of element parts of machinery within the company. By clarifying the physical phenomena of the deterioration of element parts damaged in severe environments for equipment, the company is advancing user-oriented development and is trying to open the road of diversification to industries other than the steel industry.

3 Technical Topics

3.1 Ultra-Short Term Blast Furnace Revamping Technology

In order to shorten the period of suspending pig iron supply, the huge-block ring construction method was developed for the No. 6 blast furnace of Chiba Works and revamping of the furnace was completed in 62 days which corresponds to a half of the period required by conventional methods.

The outline of this method is shown in **Fig. 6**. This method takes out the old blast furnace body by disassembling it into large blocks. The new furnace body is made in advance in four blocks of a ring-type structure divided vertically and those blocks are assembled in place one by one while being lifted-up. According to the conventional method, the body is taken out by cutting

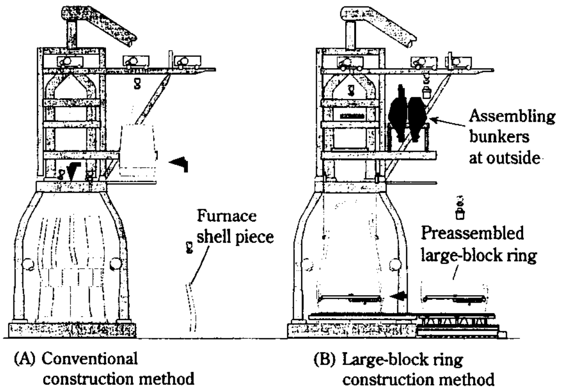


Fig. 6 Comparison between conventional construction method (A) and large-block ring construction method (B)

into small blocks of a weight of several tens of tons each, whereas, in the case of this new method, the old furnace was taken out by cutting it into large blocks of a ring shape, each weighing 1 000~1 600 t. Furthermore, the conventional method of installation was to assemble steel shell pieces of several tens of tons by welding them on the spot and then to put about 500 staves into furnace one by one. On the other hand, according to the new method, the above mentioned staves were also assembled in the ring-shaped shell pieces beforehand. The large blocks of the furnace body having a weight of about 2 000 t were carried onto the foundation and assembled one by one from the upper block to the bottom by lifting them up.

The technologies which made this method possible are as follows:

(1) Large structure analysis technology required for temporarily lifting 2 000 t blocks or for lifting the entire furnace body which weighs about 5 000 t

(2) Analysis processing processor KBSD[22] developed for efficient evaluation of stresses in thousands of parts in as many as 100 cases of loading conditions

(3) Analyzing technology for steel structure of a complex refractory structure

(4) High-accuracy welding and processing technology which has made it possible to manufacture steel shell pieces of almost 20 m in diameter with an accuracy of a few mm and to eliminate a site facing work

(5) Heavy weight lifting equipment and combined application technologies of the equipment developed in the Kawasaki Steel group

By developing this revamping technology, the company could restrain the decrease in production while revamping the furnace and could realize a reduction of repair cost and the intrinsic safety of works through extensive reduction of on-site work.

This method will also be adopted for revamping of the No. 4 blast furnace of Mizushima Works scheduled for the fall of 2001.

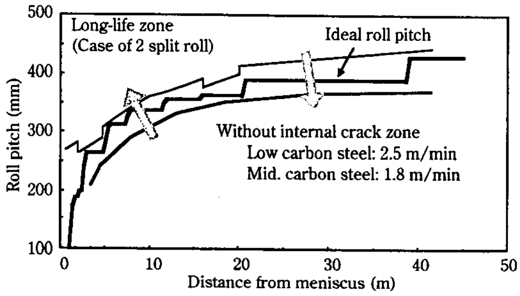


Fig. 7 Concept of roll pitch decision at Mizushima Works 4CC

3.2 High Quality Continuous Casting Technologies

Continuous casting is a complicated process with the nonlinear mechanics and elevated temperature properties of materials getting tangled together in addition to various phenomena such as solidification, heat and mass transfer, steel flow and segregation. In order to obtain high-quality slabs without any defect, it is necessary to quantitatively clarify various phenomena which affect on defects and to make the operating conditions and equipment specifications proper. With respect to inner cracks in slabs, in particular, there is no way to remedy or remove them during the rolling process. For this reason, the company established a method to quantitatively analyze the effects of various conditions such as secondary cooling speed and roll pitch on strain in solid shells and a method to predict the generation of defects for each kind of steel[23,24] and has made high efficiency casting of high quality slabs possible. The roll profile of No. 4 continuous casting machine of Chiba Works and the No. 4 continuous casting machine of Mizushima Works (Mizushima 4CC) were decided on the basis of this technology[25,26] and at the latter, proper roll pitches which realize both avoidance of inner cracks and long-life of equipment were determined accordingly and a high speed casting of 2.5 m/min was achieved as shown in **Fig. 7**.

On the other hand, high cleanliness is strongly required for steel strips such as those used for automobiles in recent years and high purity cleaning systems are important for molten steel in continuous casting. For the purpose of reducing the cost of refractories, tundish hot recycling has been adopted at Mizushima 4CC, however, if heated by ordinary combustion flame, adhered metal is oxidized and the cleanliness of molten steel at the time of casting starts deteriorates. In order to solve this problem, a non-oxidizing heating system using high temperature N_2 gas was developed. With this new system, production of very clean high quality slabs was made possible even when using tundish hot recycling.

For steel plates and bar and rod products, strong need exists for the reduction of central segregation which

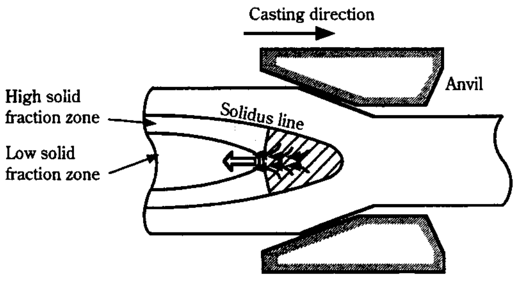


Fig. 8 Concept of continuous forging process

causes deterioration of mechanical properties. Central segregation is a defect where various noxious elements such as P and S are concentrate and segregate to the section center of a slab where final solidification occurs. For reduction of these defects, various methods have been proposed including electro magnetic stirring and soft reduction with rolls. First of all, the company modeled the generation of central segregation and established a method to quantitatively estimate segregation. Then by combining this method with a method to analyze dynamic deformation of slabs at big reduction, the company independently developed a continuous forging process which stands above what traditional common sense would dictate as posible.[27] As shown in **Fig. 8**, the solute concentrated liquid at the final stage of solidification is forcibly discharged by forging with anvils, therefore, central segregation is completely eliminated. The system of this process was also independently designed by the company and has been actually used in Mizushima 3CC, and thus has been making a large contribution, toward improving the quality of high-grade bar and rod products.

3.3 Endless Rolling Technology

In constructing the No. 3 hot rolling mill of Chiba Works, the company challenged the limit of hot rolling technology on the basis of technologies developed for hot rolling equipment and technologies at Chiba and Mizushima Works. In addition to applying an advanced automatic production system which made production possible with a small number of personnel, for below the traditional number required by common sense, the latest control method for strengthening the quality competitive power and the control system, the company developed continuous or endless rolling technology, which can be regarded as a technological innovation leading the world[28]. This endless rolling process is capable of dramatically improving the stability of rolling by avoiding non-steady deformation at the top and tail ends in the finishing mill and at the same time, is capable of markedly enhancing the quality of hot rolled plates by reducing dispersion in plate thickness, finishing temperature, etc. Furthermore, this process has made production of various products possible including ultra-thin hot strips of 0.7~1.2 mm thick[29] which correspond to conventional cold rolled products, ultra-deep drawable strip with an r-value exceeding 3.0 produced by application of hot strip rolling with lubrication[30] and deep drawable stainless steel plates. Thus the company realized the long-standing dream of engineers and researchers in the world who are engaged in hot rolling.

The company definitely commenced definite development of the endless rolling technology from the mid-1980's. By starting with joining tests using models and going through full-scale joining and rolling tests in the No. 1 hot strip mill, the company successfully completed the development for the first time in 1995 with the No. 3 hot strip mill of Chiba Works. **Figure 9** shows the major technologies[31] which were developed in order to actualize endless rolling. The major technologies are as follows:

(1) Bar-joining technology to join the tail end of the foregoing bar to the top end of the following bar in a short time of less than 5 s

(2) Joint surface cutting technique (debarring) for the

Newly developed technologies for endless rolling		
Control technology	Bar-joining technology	Coiling technology
· Mill-pacing control · Catching-up control	· Bar-joining · High-accuracy rolling · Deburring	· High-speed shearing · Ultra-thin-strip threading

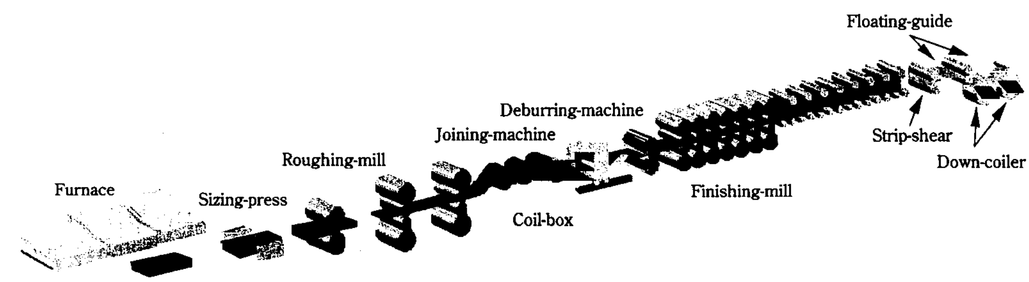


Fig. 9 Layout for endless rolling in Chiba Works No. 3 hot strip mill

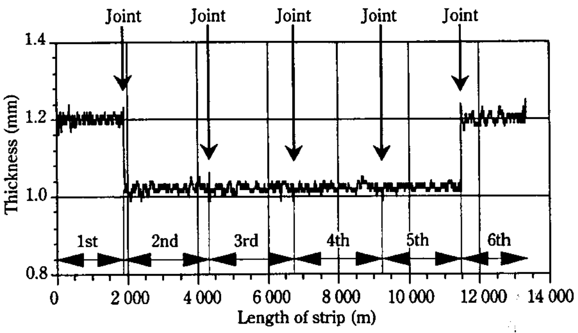


Fig. 10 Strip thickness of endless hot strip rolling measured by X-ray thickness meter at F 7 delivery point (strip thickness: 1.2 → 1.0 → …… → 1.0 → 1.2 mm)

purpose of preventing rupture at finishing rolling at joints

(3) High accuracy finishing tension and shape control techniques and flying gauge changing technique for stably producing strips freely at any thickness
(4) Strip-shear technique for high speed cutting of plates at 1 150 m/min
(5) High speed strip carrying system to stably carry the top end of strips of less than 2.0 mm thick
(6) Mill pacing technology to control carrying pitches on the basis of high accuracy material tracking estimation and experience
(7) High accuracy catch-up control system[31] to join the top end of following material to the tail end of foregoing material just in time at a predetermined position of the joining machine

Figure 10 shows a strip thickness chart of endless rolling. This is an example of the flying gauge changes of strips, with a thickness of 1.0 mm, which were considered difficult to roll by conventional universal mills, by joining to strips of 1.2 mm thick. By this method of flying gauge change, the rolling troubles which occur in the non-steady part at the top and tail ends could be prevented and a thickness accuracy of 7 ± 30 μm was achieved throughout from the first material to the last. Flying gauge changes were made in a very short time of less than 0.5 s and no thickness fluctuations were found with this process.

With the high accuracy and high reliability complete automation technologies as the foundation, the endless rolling has been realized as an unprecedented comprehensive technology of machinery and control.

3.4 Hot Rolling Finishing Mill Optimal Control

As the methods for process control, there are such methods that are based on control theories treating dynamic phenomena[32], various optimization methods[33] for determination of optimal conditions and other methods such as the expert system, fuzzy control and neural network methods[34] simulating the process of thinking of living things. Kawasaki Steel has been developing control theories for continuous forging and hot rolling[35–38], optimization technologies for raw material handling, hot rolling, etc.[39,40] and control technologies based on artificial intelligence for blast furnaces, cold rolling, etc.[41,42] An example of a hot rolling finishing mill optimal control is explained in the following (**Fig. 11**).

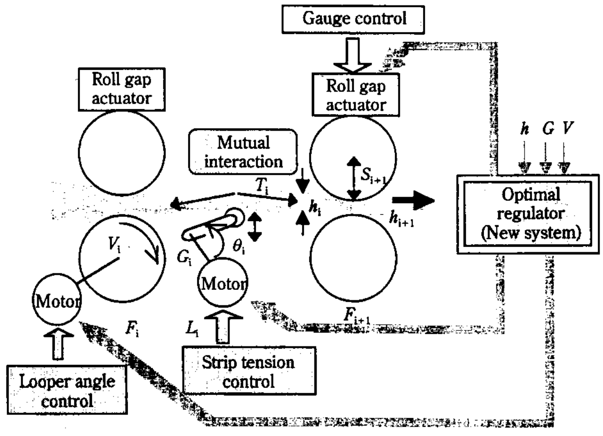


Fig. 11 Outline of the conventional control system and the optimal control

In the case of conventional hot rolling finishing mills, the gauge control system for adjusting thickness, the tension control system for adjusting tension and the looper angle control system for adjusting the balance of velocity between stands functioned independently. However, mutual interference exists between tension, looper angle and thickness. Therefore, when the control gain was increased in order to improve control performance, some problems such as hunting in the systems appeared and sufficient or satisfactory control could not be actualized. In order to solve these problems, an optimal control system which operates the mill with the roll gap, roll speed and looper torque in harmony was formed and applied to actual mills. As a result, the control performance could be extensively improved and fluctuation in thickness could also be reduced by about 10% even with the same level of control gain as in conventional systems (**Fig. 12**). Furthermore, fluctuation in looper height and tension could dramatically be reduced to about 1/4 and 1/2 the previous levels respectively.

4 Future Perspective

The steel industry in Japan has run into an age of large reformations in the international currents; severe competition, consolidated accounts, supplier selection by customers, environmental protection, rapid progress

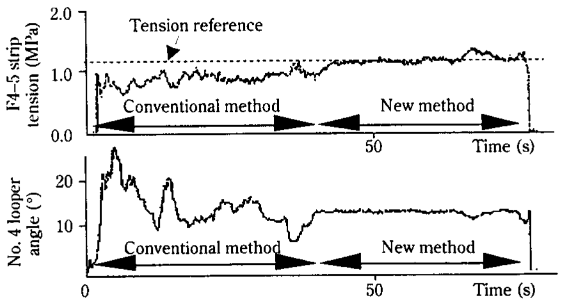


Fig. 12 Result in the actual production mill

of information technology, etc. and improvement of management efficiency and maximization of profitability of assets including group companies have become important subjects for business management. For the steel industry as a process industry, an important direction in the future should be to communize the so far built-up equipment technology power by the group altogether and widely contribute to the community.

With respect to process technologies, it is necessary to further strengthen technological development with various matters including environmental protection, quick response to diversified customers' needs and cost reduction to cope with this era of severe competition. For example, it is considered important to develop and commercialize new technologies for the future of the earth including production technology for ultra fine grain steel, production technology for environmentally friendly steel products, recycling technology for waste heat recovery technology, recovery technology for medium and low temperature range waste heat and energy recovery technology applied to chemical reactions.

On the other hand, control technology and information technology are fields where technological progress is most remarkable at present and further increases in speed and capacity are expected together with reductions in cost. With such a trend, advanced control theories, simulation technologies, data base control systems, etc. will be developed to the level of practical use and will become strong weapons for quick development of new products and improvement of steel manufacturing technologies.

As for equipment management technologies, it is necessary to make great strides in effective equipment management systems by advancing life extension technology and highly efficient construction technology for repair work including the maintenance support system, equipment diagnosis technology, evaluation and analysis technology and development of new materials. Additionally, remote maintenance and remote maintenance at home utilizing information technology will be realized and establishment of maintenance systems with a selected few personnel, improvement of the rate of operation, etc. can be expected. On the other hand, micro-machining technology will also be advanced with further miniaturization and improvement of learning ability as seen in the appearance of pet robots and is expected to expand its fields of application to works under three severe conditions; hazardous, dirty and hard, equipment monitoring work, etc.

As explained in the above, there are possibilities to greatly change the form of steel works' operation by taking rapid technological development in various fields into account and by systematically combining the results of such development. It is important to study and develop new technologies and application technologies while correctly ascertaining the trends. In order to tie such efforts to new revolutions in steel production, Kawasaki Steel is eager to positively tackle the development of new technologies while exactly grasping the technological trends which the customers are pointing.

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