

# Technical Developments for Steelmaking Machinery

Naoki OISHI\*  
Yasushi KURISU  
Yuichi ISHIMORI

Yoshiaki SHIA  
Kazumichi WADA

## 1. Introduction

In order to meet contemporary social needs, including resource saving and CO<sub>2</sub> reductions, Nippon Steel Corporation has pursued the development of new technologies, such as continuous production processes, operational improvements for high efficiency, and the development of high quality output, such as high-tensile steel products.

In this technical review, we describe the component technologies the company has developed in the field of mechanical engineering to help enhance the functions of its steelmaking equipment so as to meet the above needs, with emphasis on the progress, achievements, and future trends of equipment diagnostic technology, which has revolutionized equipment maintenance/management by making it possible to monitor the operating condition of the equipment and identify trends in the deterioration of equipment; technology that has significantly improved the durability of the main components in the equipment, and technology for coating rolls, etc., all of which have contributed to improved product quality through optimization of the runner/conveyor parts' surfaces.

## 2. Evolution and Future Progress of Equipment Diagnosis Technology

In order to ensure stable operation of production equipment and cut equipment maintenance costs, it is essential to implement predictive maintenance to plan for repairs at the best time while grasping the degree of equipment deterioration (condition-based maintenance). As a means of grasping any signs of equipment deterioration early and quantitatively, Nippon Steel developed equipment diagnostic technology for the rotating machines. Next, we created practical diagnostic system and soon thereafter introduced

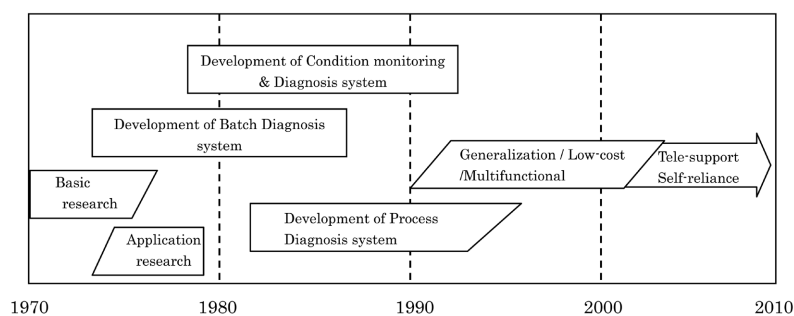
it to the manufacturing sites.<sup>1)</sup>

The underlying concept of equipment diagnosis technology is to build diagnostic logic by verifying the causal relation between the symptom of deterioration and the signal detected for each of the mechanical parts' elements. Sensors, signal processors, etc. which are required for that purpose might seem to be combinations of technologies in the field of instrumentation. At Nippon Steel, however, the Mechanical Engineering Department has engaged itself in the development and assurance of those technologies, since equipment diagnosis technology is intended basically to monitor the operating condition, determine the mechanisms of deterioration, and manage the operational trends of mechanical equipment.

For example, the company developed a technique to diagnose deterioration in the bearings and gears of rotary machines, which account for a large proportion of our steelmaking equipment. In cooperation with Nittetsu Elex Co., the company has evolved that technique into a portable multifunction diagnostic device ("ELESMA<sup>TM</sup>") which the conservation can measure during inspection patrols of the equipment. The device has become one of the most convenient tools for measuring equipment deterioration.

In recent years, the company has developed an on-line diagnostic system to help with long-term trend management and measurement tasks for important equipment. The types of equipment to which the system can be applied have been increased and the functions of the system have been enhanced. More recently, the company has put to practical use an acoustic diagnostic technique that permits diagnosing even low-speed revolving machines, like the rolls of continuous casting equipment, which formerly proved difficult to diagnose. This is an example of the functional enhancement of the above system.

**Fig. 1** shows how Nippon Steel's equipment diagnosis technology



**Fig. 1** History of condition diagnostic technologies

\* General Manager, Mechanical Engineering Div., Plant Engineering and Facility Management Center 20-1, Shintomi, Futtsu, Chiba 293-8511

has progressed.<sup>2)</sup>

Incidentally, the multifunction diagnostic device and the on-line diagnostic system introduced above are widely used both inside and outside the company, and won the TPM Good Product Award of the Japan Institute of Plant Maintenance.

On the other hand, some forty years have passed since the first integrated steelworks were constructed, and the long-term deterioration (corrosion, etc.) of old outdoor steel structures has become conspicuous. Therefore, the company has introduced efficient obsolescence diagnostic techniques that apply the latest surveying technology or nondestructive inspection technology. For example, the deflections of members of the outdoor belt conveyor frames and raw materials stackers, etc. are measured by a three-dimensional laser scanning method and the measurement results are used to ensure the prescribed operational accuracy and diagnose the deterioration of those machines. The three-dimensional laser scanning method is also used in combination with FEM to speedily diagnose the yield strength of structural members whose thickness has been reduced by corrosion so as to prioritize repairs or renewal of damaged or obsolescent machines. The above technology has already been applied to many structures and outdoor machines.

In the future, in view of the characteristic of steelworks having widely scattered equipment, by building an advanced autonomic on-line diagnostic system that combines portable communication, power-saving radio and energy harvesting, it will become possible to implement ubiquitous maintenance information management at reasonable cost. In order to prevent any diagnostic system from interfering with maintenance personnel, technology that monitors their own system and sensors while conducting checks for themselves will have also been put to practical use.

### 3. Progress and Future Trends of Life Extension Technology

#### 3.1 Life extension technology

The rollers and other main components of steelmaking equipment and the various parts of equipment exposed to dust/ore flows are susceptible to severe damage caused by abrasion, thermal stress, and corrosion, etc. Therefore, controlling their functions for an extended time and minimizing the maintenance costs have long been difficult problems.

In order to reduce the above damage, the company has positively applied corrosion-resistant steels and titanium against corrosion, and ceramics and other bulk materials against abrasion. Since abrasion and thermal stress of structural members originate from their surfaces, it may be said that surface coating technology and surface processing technology which improve the surfaces of materials, such as welding, thermal spraying and plating, are effective and economic means of extending the life of steel parts. Therefore, Nippon Steel has applied those surface improvement technologies to the steelmaking equipment.<sup>3)</sup>

For example, in the field of thermal spraying technology, the company has been introducing the various seeds of related technologies and has developed their application to steelmaking equipment from early on as shown in Fig. 2.

Since the steelmaking equipment is operated under extremely high temperatures, high pressures, and heavy loads, etc., Nippon Steel has developed original thermal spraying materials and processes jointly with specialized makers, including Nippon Steel Hardfacing Co.

Amongst the various thermal spraying techniques, high-velocity

		1985	1990	1995	2000
Concept		Life extension of steel plant • Cost reduction of maintenance		Higher durability • Maintenance Prevention	
History of introduction		◆ PTA (plasma transferred arc welding) ◆ D-gun Wire flame spraying SFA (self-fluxing alloy coating)		◆ CVD, PVD ◆ HVOF ◇ Advanced HVOF	
Subject of application	Iron making plant & Steel Making plant	○ Blower		◎ Blower (extended life)	
	Hot rolling plant	○ CC mold		○ Boiler tube & hood etc.	
	Cold rolling & Plating plant	○ Sink roll		○ Processing roll	
				○ Processing edged tool	
		○ Hearth roll		○ Processing roll (B/R roll) etc.	

Fig. 2 Application of thermal spraying in steel making plants

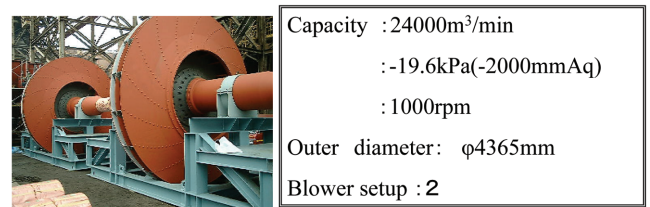


Fig. 3 Example of WC-Co coated blower of sinter machine

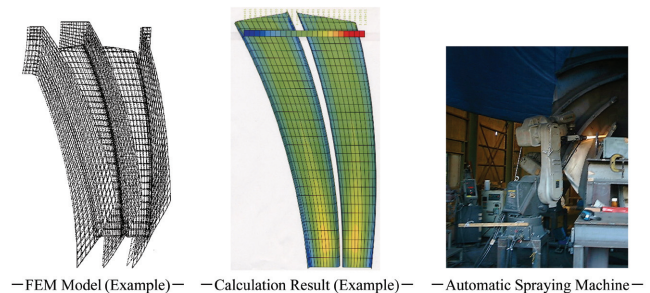


Fig. 4 Analysis for stiffness design of blower, automatic spraying system

oxygen-fuel spraying process has been mainly applied to steelmaking equipment. In recent years, the company has also been pressing ahead with an activity emphasizing improvement of the technology that reflects the function of sprayed film in the design in order to further improve the durability of the film.

Figs. 3 and 4 show an example in which hard WC-Co thermal spray coating applied to the rotor of the main blower of a sintering machine.<sup>4)</sup> In this example, the period of the blower repair that determines the major shutdown period for the sintering machine was maximized in order to improve the availability of the sintering machine. In the case of a large blower, the thermal sprayed surface is susceptible to deflection and the reliability of the surface film against cracking and separation, etc. is difficult to ensure reliability. In this respect, the company has developed a new technology that permits obtaining a film thickness twice that of the ordinary film through optimization of the residual stress at the thermal sprayed surface, implementation of the optimum runner stiffness design, and

		1970~	1980~	1990~	2000~	2010~
Submerged arc Welding	13Cr-Ni Type	◇Roll repairing (preferable balance of oxidation resistance & heat-resistance)				
	Cr-Ni Stainless Steel Type		◇ Powder resistance	※anticorrosion		
Thermal Spraying	13Cr-Ni wire flame spraying +Self-Fluxing Alloy coating	◇ Resistance for operation interruption ※cracks in the surface are dispersed at random direction (effective material)				
Plasma Transferred Arc Welding	High-Alloy materials			※increase of strength at high temp. & corrosion resistance		

Fig. 5 Overview of CC-roll hard facing

automation of the thermal spraying operation. As a result, the intervals between blower repairs have been extended from less than two years to more than four years.

In addition, the company has developed new overlaying materials. As an example, the extension of life of the segment rolls in the continuous casting machines can be noted.

When it comes to repairing continuous casting rolls which have been replaced because of thermal cracking, wear or corrosion, overlaying with 13Cr-based martensitic stainless steel, which has good corrosion resistance and is comparatively free of thermal cracking, has been widely employed with the aim of improving the roll surface durability. As a result, the period of CC segment replacement has been extended and the factor that determines the roll life has changed from roll damage to the bearing life.

With the subsequent change in equipment operating conditions, greater durability of the roll surface is now required. Therefore, the company has developed and put to practical use new high-alloy overlaying materials for those parts which demand superior corrosion resistance and new self-fluxing alloy spraying materials that are capable of dispersing fine cracks for those parts which demand superior resistance to thermal cracking. Fig. 5 shows the main weld materials that have been developed so far. The company has also studied optimizing the roll surface profiles and reducing their thermal stresses by means of FEM analysis, etc.

From the standpoint of ensuring stable operation of the steelmaking equipment under a severe environment, developing new technologies to extend equipment life has become increasingly important. We intend to continue pressing ahead with activities to build the optimum equipment in terms of the diagnosis, materials, and construction/design methods used by incorporating into the equipment design the above technology for quantitative diagnosis of equipment deterioration and advanced materials.

### 3.2 Coating technology for the rolls of steel processing lines

New materials, including ceramics, and new coating techniques are developed at a rapid pace. As mentioned above, new materials and coating techniques suitable for steel equipment have been continually developed and put to practical use, contributing much to the extension of equipment life and the enhancement of equipment capability.

Concerning the rolls and other parts of steel processing lines, large components for steelmaking equipment can hardly be made from bulk ceramics alone. In practice, therefore, their surface is coated with a spraying of ceramic or cermet, whereas the required strength, toughness, etc. are ensured by using a suitable base metal. Thus, coating technology is the key to practical use of materials for those parts. Since the 1980s, various thermal spray coatings appropriate for specific working conditions have been developed and put to

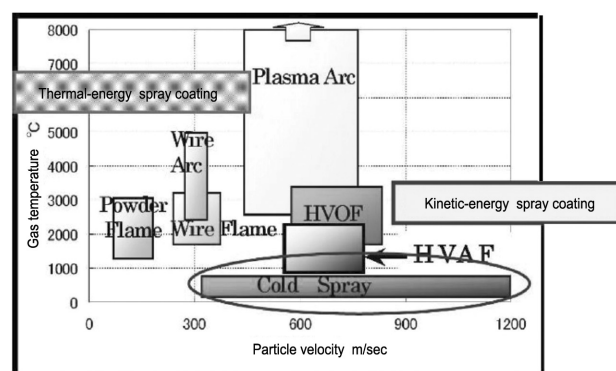


Fig. 6 Operating gas temperature and particle velocity of spray coating method

practical use.

#### 3.2.1 Spray coating technology trends for rolls of steel processing lines

There are many spraying methods, such as gas spraying, self-fluxing alloy spraying, and plasma spraying. Since high velocity oxygen-fuel (HVOF) spraying that permits the formation of dense films with high-speed projection of the coating material powder was developed in the 1980s, films formed by HVOF have been widely applied to the rolls for steel processing lines.

In recent years, positive efforts have been made to develop new spraying processes that are capable of applying the coating material powder at higher speeds. For example, cold spraying that can spray the powder at Mach 2 to 3 has been developed (see Fig. 6)<sup>9)</sup>.

As representative examples of the application of coating film to rolls for steel processing equipment at our company, we describe below the latest trends in the development of films for the hearth rolls of continuous annealing furnaces and the pot rolls of hot-dip galvanizing equipment.

#### 3.2.2 Hearth rolls of continuous annealing furnaces

In a continuous annealing furnace (C.A.P.L.<sup>®</sup>, CGL) which is a vertical type, steel strip is conveyed by hearth rolls in a high-temperature reducing atmosphere. In the furnace, the iron powder that has been produced in the rolling process or the oxide layer on the surface of the steel sheet is reduced and becomes active, causing the iron and iron oxide to react with or coagulate on the roll surface film and thereby produce an iron-based buildup. The buildup on the roll surface can cause dents in the steel sheet, which in turn can cause deterioration in the quality of the steel product. In order to prevent such buildup, a cermet film composed of an oxide ceramic and a heat-resistant alloy has been widely used.

In recent years, however, damage to steel surfaces caused by the buildup of some nonferrous element has been increasing.

Accordingly, in order to spread the range of material choice for cermet films, Nippon Steel has developed technology that permits dispersal of ceramic particles even with such oxide materials that cannot form a dense film itself at the mixing stage for the raw material powders. Then, in cooperation with Nippon Steel Hardfacing and other spray makers, the company has put to practical use a new dense cermet film that is free from deterioration and that hardly produces any buildup even when used at high temperatures for many hours.

### 3.2.3 Pot rolls of hot-dip galvanizing equipment

In the CGL, the steel strip is fed from the annealing furnace into a zinc-plating bath via a snout, in which bath the direction of the strip is forced upward by sink rolls and its deflection is corrected by support rolls. After that, the zinc coating thickness of the strip is adjusted by the wiping nozzles outside the bath.

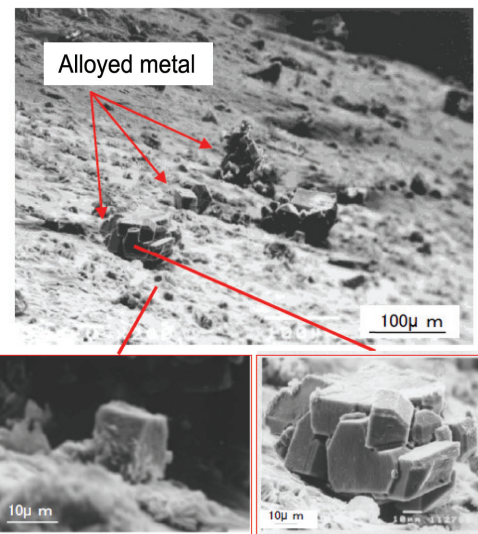
In the plating bath, iron eluted from the steel strip combines with both zinc and aluminum, which are component elements of the bath, to form dross. The dross formed tends to stick to the surfaces of the sink rolls and support rolls in the bath, causing slip marks, dents, etc. in the strip surface.

**Fig. 7** shows an example of dross that was formed on the spray film on the surface of a roll in the zinc bath. It can be seen from the figure that the dross formed on the film surface was growing.

In order to restrain the deposition of dross on the rolls in the plating bath, it is necessary that the film on the roll surface should have not only corrosion resistance against zinc but also such a disposition that dross can hardly occur or attach to it and that any dross formed on it can be removed easily. At present, we are studying new spray films that meet the above requirements.

## 4. Conclusion

As described so far, in order to meet the ever-growing demand for enhanced equipment availability and better product quality, etc. from a mechanical engineering standpoint, Nippon Steel has developed, by itself or in cooperation with other members of the Nippon Steel Group, new materials and essential technologies,



**Fig. 7** SEM image of alloyed metal nucleus on spray coating

including coating technology, and has put them to practical use at the steel manufacturing sites, thereby contributing to the progress of maintenance technology. In the future, we intend to continue our R&D on maintenance technology while paying careful attention to the prevailing trends in terms of needs and seed technologies.

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Naoki OISHI  
General Manager  
Mechanical Engineering Div.  
Plant Engineering and Facility Management Center  
20-1, Shintomi, Futtsu, Chiba 293-8511



Kazumichi WADA  
Manager  
Machinery Maintenance Technology Dept.  
Mechanical Engineering Div.  
Plant Engineering and Facility Management Center



Yoshiaki SHIA  
Department Manager  
Machinery Maintenance Technology Dept.  
Mechanical Engineering Div.  
Plant Engineering and Facility Management Center



Yuichi ISHIMORI  
Manager  
Machinery Maintenance Technology Dept.  
Mechanical Engineering Div.  
Plant Engineering and Facility Management Center



Yasushi KURISU  
Senior Researcher  
Mechanical Research Dept.  
Mechanical Engineering Div.  
Plant Engineering and Facility Management Center