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Nippon Steel Type Tundish Plasma Heater "NS-Plasma I" for Continuous Caster


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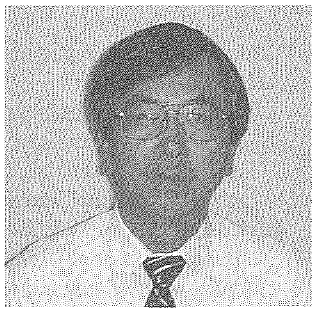
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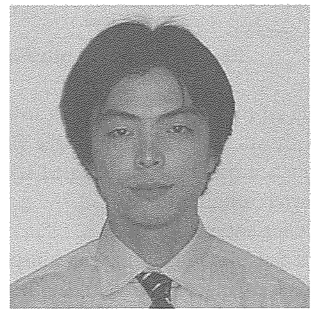
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Abstract

In continuous casting, the fluctuation of the molten steel temperature gives adverse effects on the cast strand quality by forming non-metallic inclusions or causing segregation, and on stable operation by causing nozzle clogging or break-out. One of the techniques to solve such problems is tundish plasma heating system. Nippon steel developed the compact type tundish plasma heating system "NS-Plasma I" based on total technologies raised for a long time. In this paper, the features and effects of this system are outlined.

1. Introduction

Needs are felt more and more strongly for reduction of steel production costs, production of higher-grade steels and small volume production with variety in sizes and grades in the continuous casting process. The control of molten steel temperature in a tundish is one of the measures to satisfy the needs. This is a technology to control the steel temperature within an optimum range by heating the molten steel with a plasma arc formed on the surface of the molten steel in the tundish. The optimization of the steel temperature not only greatly reduces the costs of refractory and energy at the processes upstream of the continuous casting, but also brings about advantages such as homogeneous quality of continuously cast steel and stable operation.

Nippon Steel developed a new tundish plasma heating system named "NS-Plasma I" on the basis of technologies covering all the aspects related to tundish plasma heating systems, including an in-house developed plasma torch, optimum plant engineering technologies and operation know-how accumulated over a long period. This paper reports the characteristics of the developed system.

2. Characteristics of Tundish Plasma Heating System

NS-Plasma I is a system for controlling the molten steel temperature in a tundish, having a plasma torch installed over the surface of the molten steel in a tundish used as a cathode and steel plates arranged in inner walls of the tundish as anodes, so as to heat the molten steel with a plasma arc formed between the plasma torch and the molten steel by applying an electric current between the cathode and the anodes. The configuration of the system is shown in **Fig. 1**.

The plasma heating has the following advantages[1]:

1) High temperature

NS-Plasma I uses argon as its working gas. The working gas, when ionized, emits a great amount of energy and a temperature far higher than attainable by combustion gas or other means is obtained. The temperature at the center of the argon plasma is estimated at 10,000K or higher.

2) Clean heat source

Since the molten steel is heated in a clean atmosphere of inert argon gas, deterioration of the molten steel such as oxidation, nitriding, carbonization is much suppressed compared with the heating by

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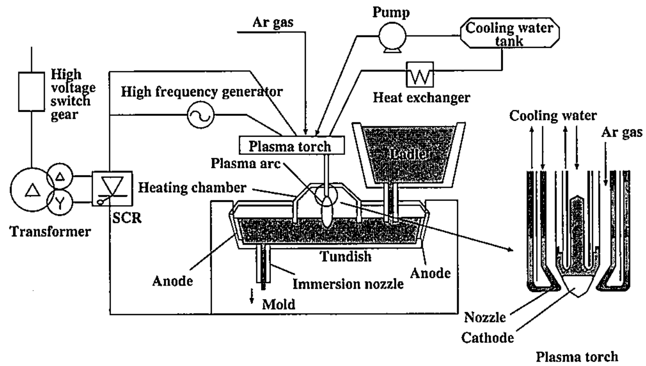


Fig. 1 Configuration of NS-Plasma I

combustion gas or electric arc using a carbon electrode. For this reason, the cleanliness of the cast steel is not affected by the heating.

3) Easy control

The required output of the plasma can be easily set in a wide range through the control of electric power input. Owing to quick response of the plasma heating, the heating of the molten steel begins immediately upon energizing the plasma circuit, and therefore, intensive heating is possible even during non-steady state operation such as change of ladles.

3. Effects of Plasma Heating

3.1 Temperature Compensation of Molten Steel in Tundish

The temperature of the molten steel in a tundish falls inevitably at the beginning and end of casting and change of ladles, as shown in **Fig. 2**, as a result of heat absorption of refractories and radiation from the steel surface. Since the fall of the steel temperature slows down floatation separation of non-metallic inclusions in the steel and causes problems such as clogging of immersion nozzles, when the continuous caster does not have the function to heat the molten steel in the tundish, it becomes necessary to raise the steel temperature at tapping from a steelmaking furnace to compensate the temperature fall.

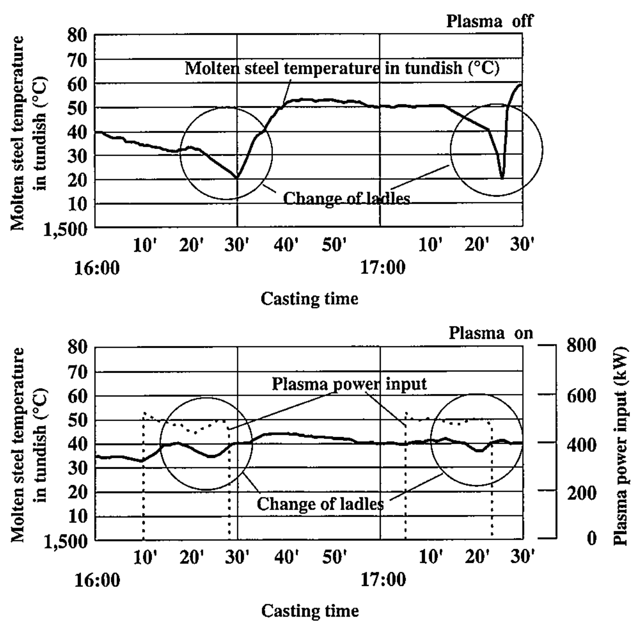


Fig. 2 Example of molten steel temperature control

When the plasma heating is used for temperature compensation at the tundish, the tapping temperature of the steelmaking furnace can be lowered and the costs of refractories of the furnace and ladles and energy input for the tapping can be reduced[2)].

3.2 Temperature Control of Molten Steel in Tundish

3.2.1 Improvement of cast steel quality

To obtain a good internal quality of the cast steel, it is necessary to reduce both non-metallic inclusions and center segregations to the best possible extent. As shown in **Fig. 3**, the molten steel temperature in the tundish has a great influence on the cast steel quality: when the temperature is too low, the non-metallic inclusions increase and, when it is too high, the segregations increase[3)].

With the tundish plasma heating, it is possible to prevent casting temperature from fluctuating and control it within an optimum range, and thus, to maintain good quality of the cast steel.

3.2.2 Stable operation

The fluctuation of the casting temperature also adversely affects the operation of the caster. When the molten steel temperature in the tundish is too low, deposition of the steel and non-metallic inclusions on the inner surface of the immersion nozzles increases, causing their clogging. The clogging of the nozzles not only hinders stable operation of the caster but also causes steel flow into the mold to fluctuate, resulting in deterioration of the cast steel quality such as poor surface quality owing to uneven powder supply as a result of fluctuating molten steel level in the mold and entrapment of inclusions owing to unsymmetrical steel flow in the mold. When the casting temperature is too high, on the other hand, formation of solidification shell in the mold becomes insufficient and unstable, leading to problems such as breakout. Occurrence of these problems is reduced and productivity is improved through the temperature control by the developed system.

Fig. 4 shows the effect of the plasma heating to reduce the occurrence of the immersion nozzle clogging. It is possible to know the degree of nozzle clogging from the stopper height because, generally in the case of a tundish using stoppers, the height of a stopper increases as the clogging proceeds[2)]. For this reason, the stopper height is used as the indicator of the nozzle clogging in Fig. 4. In the figure, the nozzle clogging is seen to decrease by about 20% when the plasma heating is applied.

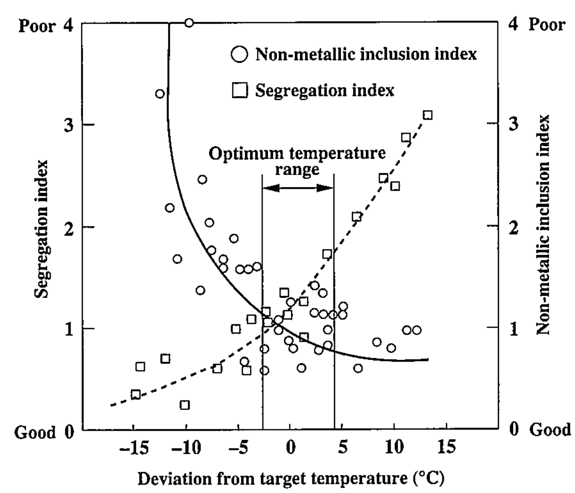


Fig. 3 Relation between target temperature of molten steel in tundish and cast steel quality

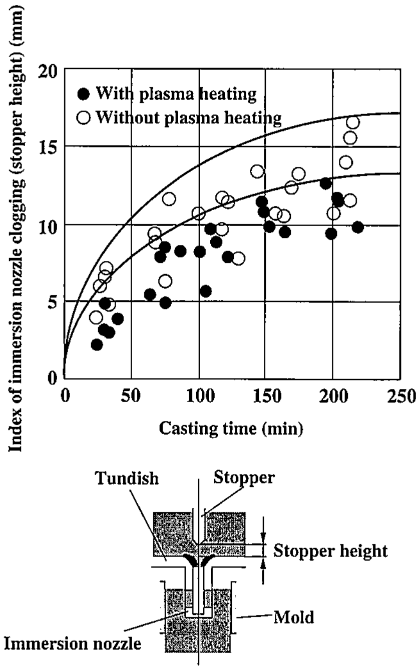


Fig. 4 Nozzle clogging suppression effect of plasma heating

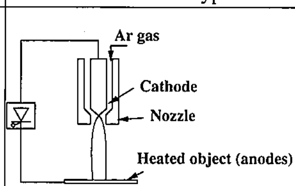
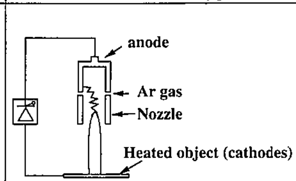
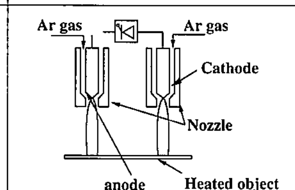
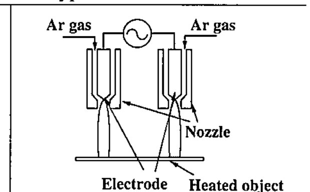
4. Plasma Torch

Common types of plasma torch applicable to the tundish plasma heating are shown in **Table 1**. The plasma torches for the tundish plasma heating are classified into two types according to the number of torches used in a unit: single type torches and twin type torches.

The single type torches, which use the torch itself and steel plates arranged in the tundish as the electrodes, are classified further into hot electrode type and cold electrode type by the plasma arc emission method. The hot electrode type torches use thermionic emission for the electron emission for plasma discharge, and the temperature at the tip of the plasma torch becomes as high as several thousands of degrees Celsius[4]. Since the construction of this type is simple and the size is small, the manipulator, piping and cabling connected to the torch can be compactly designed, and accordingly, it is applicable to small and middle size continuous casters in which the space between the ladle and the tundish for insertion of the plasma torch is small. In contrast, in the cold electrode type torches, in which the electrons are supplied by field emission, the temperature of the electrode surface is comparatively low, several hundreds of degrees Celsius. Because of the comparatively low temperature of the electrode surface, a large power output can be obtained. However, since this type requires a large amount of working gas for stable control of the plasma arc, which is generated from inside the torch, the construction is more complicated. Consequently, the size tends to be comparatively large.

The developed plasma heating system, NS-Plasma I, uses a hot electrode, single type DC plasma torch, developed by Nippon Steel, designed so that the system can be fitted to small and middle size continuous casters. **Fig. 5** shows the number of the Nippon Steel-design torches required in accordance with different molten steel throughputs. It is clear from the figure that a sufficient heating capacity for a billet/bloom caster having a molten steel throughput of 3 t/min or less can be secured with one unit of the torch. (A throughput

Table 1 Types of plasma heating

	NS-Plasma I	Other plasma heaters		
Type of plasma torch	Single type		Twin type	
	DC			AC
	Hot electrode type	Cold electrode type	Hot electrode type	
Composition				
Power output	Small to medium	Medium to large	Large	Large
Equipment layout	Good Light weight with one torch. Compact auxiliary equipment	Rather complicated Torch is large and complicated in structure	Rather complicated Heavier with two torches. Large auxiliary equipment	Rather complicated Heavier with two torches. Large auxiliary equipment
Maintainability	Torch: Good Anodes: Good Steel plates arranged in tundish as anodes	Torch: Not so good Cathodes: Good Torch is large and complicated in structure. Steel plates arranged in tundish as cathodes	Torch: Good	Torch: Good
Stability of plasma arc	Good	Not so good Complicated control of plasma arc by working gas	Good	Not so good Arc stabilizing control required against periodical arc extinction peculiar to AC plasma
Heating efficiency	Good	Not so good Large heat loss owing to torch cooling	Good	Good

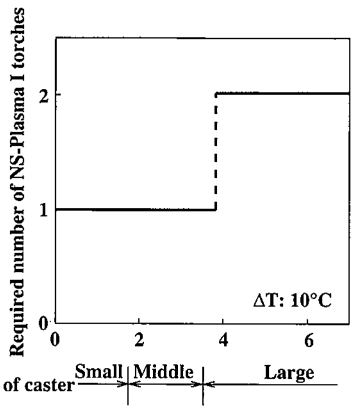


Fig. 5 Required number of NS-Plasma I units according to molten steel throughput

of 3 t/min or more can be catered for using two sets of NS-Plasma I.) It is supposed in the figure that the temperature to be raised (ΔT) of the molten steel is 10K.

The twin type torches, in which one of the torches is used as the cathode and the other as the anode, are divided according to the power source into two groups: DC type and AC type. According to the twin type, it is possible to use higher voltage and obtain higher output than the single type, but arrangement of two torches requires a larger space above the tundish. For this reason, the twin type is more suitable for slab casters having a large throughput of molten steel.

5. Characteristics of NS-Plasma I

Characteristics of Nippon Steel's tundish plasma heater, NS-Plasma I, are explained below.

5.1 Compact Design

The equipment is designed as compact as possible so that it may be fitted to any continuous caster, some of which may have only a limited space for retrofitting. Since only one plasma torch is used as explained before, the manipulator can be made compact. Inclined torch insertion and a short plasma torch (roughly 0.5 m in length) can be used in the cases that the ladle or other existing equipment interferes with the system, and thus the system is applicable to the most of continuous casters. The routes of cooling water in the plasma torch are unified into one at the nozzle and the electrode portions to simplify the piping. No chiller unit is required since normal temperature water can be used as the cooling water. Therefore, there will be no condensation on the surfaces of the torch and piping, and no danger of vapor explosion.

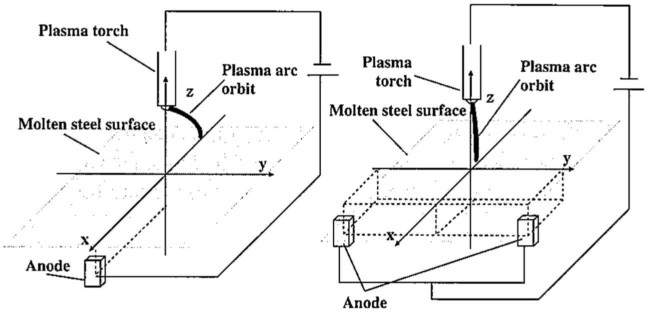
5.2 High Reliability

5.2.1 Plasma arc stabilization technology

Plasma arc is significantly deflected by the Lorentz force of the magnetic field generated by high current, and this will lead to short service life of the torch owing to abnormal melting of the nozzle portion. In NS-Plasma I, an optimum number of the anode steel plates are so arranged in the tundish to suppress the arc deflection, as shown in **Fig. 6** (b), forming an optimum system.

5.2.2 Design of heating chamber

A heating chamber for the plasma heating is formed of walls having a refractory inner lining arranged to surround the torch. Since the inner surface of the walls are heated to high temperatures by the heat radiation from the plasma arc, the life of the refractory lining is very important. For obtaining good refractory performance, a high alumi-



(a) Large arc deflection (b) Small arc deflection

Fig. 6 Plasma arc deflection

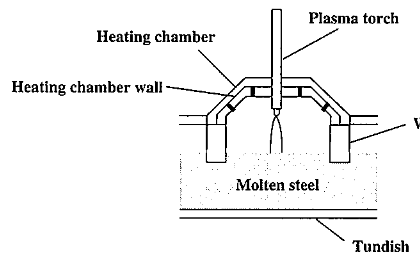


Fig. 7 Design of heating chamber

num refractory is used in the heating chamber walls and a sufficient distance is kept between the walls and the plasma arc so that the refractory may not be heated beyond its upper limit temperature.

The heating chamber is filled with argon gas but when oxygen or nitrogen is mixed, that will lead to problems such as short service lives of the torch electrode and the nozzle and ignition failure and instability of the plasma arc. A suspended weir surrounding the plasma arc is provided in the heating chamber of NS-Plasma I, as shown in **Fig. 7**, in order to maintain a high argon concentration.

The heating chamber is filled with an atmosphere of ionized plasma gas. If there is any conductive material in the chamber, the plasma arc form the torch hits not only the molten steel but the conductive material, too. This phenomenon, called the secondary arc, is responsible for many of the troubles occurring to conventional plasma heaters. To prevent the troubles from occurring, the inner walls of the heating chamber are fixed using non-conductive studs.

5.3 Full Automation

5.3.1 Temperature control

The voltage between the torch and the molten steel fluctuates as the distance between them changes. Because the level of the molten steel surface in the tundish fluctuates significantly especially during non-steady state operation such as start and end of casting and change of ladles, it is necessary to keep the distance between the torch and the molten steel constant in order to maintain the heating operation stable. The torch manipulator of NS-Plasma I has a function to automatically move the torch vertically in accordance with the change of the molten steel level, keeping the distance between the torch and the molten steel constant. The heating operation is thus kept always stable. In addition, the molten steel temperature is continuously monitored using thermocouples, and a target temperature can be set from a control panel.

5.3.2 Automatic ignition and extinction

In order to automatically ignite the plasma arc without failure and extinguish it safely, the following operation sequence is adopted in NS-Plasma I:

1) The torch is lowered toward the molten steel surface so that its tip

comes within a distance to ignite the arc without failure.
2) High frequency sparks are produced between the cathode and the nozzle.
3) A pilot arc is formed between the cathode and the nozzle.
4) The flow of the argon gas and the value of the electric current are so controlled as to move the pilot arc to the molten steel, in order that a main arc is formed between the cathode and the molten steel.
5) The power input is increased to a set value, while continuing controlling the argon gas flow, current value and torch height.
6) The arc is extinguished gradually through control of the argon gas flow, current value and torch height without decreasing the current value drastically.

Additionally, emergency measures such as automatic extinction of the plasma arc and quick retraction of the torch are also provided.

5.4 Good Maintainability

5.4.1 Maintenance of torch

The electrode and nozzle at the tip of the torch wear down by the plasma arc, and it is necessary to change them when the wear advances to a prescribed amount. A tip assembly of the cathode and nozzle is the only wear-out part of the plasma torch of NS-Plasma I and it is light in weight. Therefore it can be changed easily in a short time at the operating position. The tip of the plasma torch is shown in **Photo 1**.

5.4.2 Automatic cable coupling for anodes

An automatic cable coupling is provided for the anodes arranged in the tundish, as shown in **Fig. 8**, to automatically connect and disconnect the cabling between the main power supply and the anodes on the occasions of tundish deslagging and change of tundishes. This, then, simplifies the cabling around the tundish and shortens the the time for the connection and disconnection work.

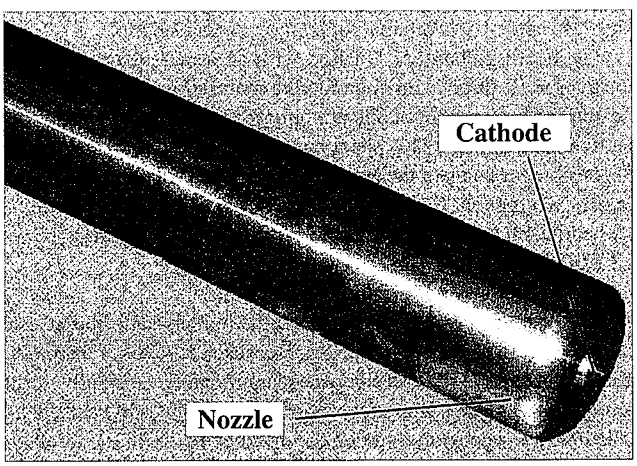


Photo 1 Plasma torch tip

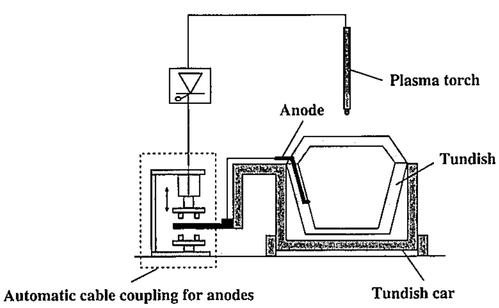


Fig. 8 Automatic cable coupling for anodes

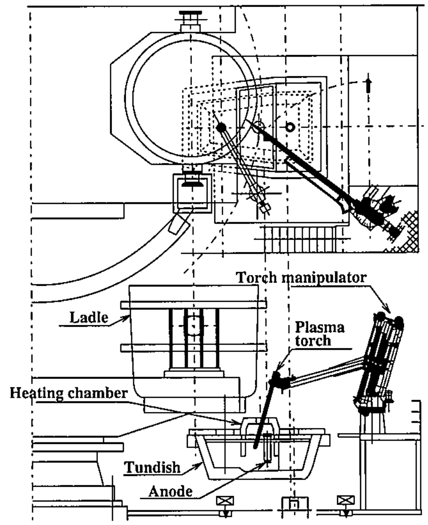


Fig. 9 Example of application of plasma heating system

Table 2 Main specification of NS-Plasma I

Plasma torch	Type	DC Plasma torch
	Electrode	Tungsten hot electrode type
Power source		DC 7,000 A (max)
Voltage		100 - 120 V (variable according to heating chamber atmosphere)
Working gas		Argon
	Flow	8-20 Nm^3/h
Seal gas of heating chamber		Argon
	Flow	50 Nm^3/h
Cooling of torch		Potable water equivalent
	Flow	120 l/min
	Water quality	Conductivity < 250μS/cm
	Temperature	< 40°C
Plasma arc length		400 mm

6. Equipment Specification

Fig. 9 shows an example of the application of the plasma heating system to a tundish, and **Table 2** summarizes the main specification of NS-Plasma I.

7. Summary

A new compact tundish plasma heater "NS-Plasma I" was introduced in this paper. The heater was developed and put into commercial use on the basis of Nippon Steel's plant operation and engineering technologies.

NS-Plasma I features the following characteristics:
- Compact design suitable for fitting to existing continuous casters as a retrofit
- High operational reliability based on optimum design
- Easy operation helped by fully automatic operation
- Excellent maintainability with easily changeable torches and quick tundish change

NS-Plasma I is expected to quickly expand its application to small and middle size continuous casters thanks to its low investment and operation costs and very large effect to improve the quality of the cast steel.

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