Mitsubishi Heavy Industries, Ltd. (MHI) has made incessant efforts to improve the performance of biaxially oriented film manufacturing plants in order to comply with the demand of high productivity of the biaxially oriented films used in various fields, and has achieved the highest operating speed on commercial production (width 8.3 m x speed 450 m/min) in the world. MHI has developed a high-efficiency cooling roll with a new-type structure equipped with straight circular channel as a process of improving the performance of the above-mentioned plant and applied the roll to the casting machine. The adoption of the high-efficiency cooling roll (heat transfer coefficient: 1.5 times) reduces the cooling roll diameter of a 450 m/min-class machine from conventional φ 2600 mm to φ 2000 mm, needing less space and improving the operability at the start-up because of the down-sizing of the machine. Further, the adoption of straight circular channel enables cleaning of the cooling channel, making a drastic improvement in its maintainability.

1. Introduction

With the increase of multi-layer films and with the new resin materials increasingly used, the plastic films used in various fields including industrial products and items for every day use, etc. have come to be applied more and more in wider fields. MHI supplies the manufacturing plants to a number of countries in the world for a global-scale, high-level production output of biaxially oriented film among various other films under increasingly high demand.

Fig. 1 shows the production process of the biaxially oriented film manufacturing plant. The polymer uniformly melted by the extruder is extruded in flat sheet from the die. The extruded molten polymer is then cooled to solidification in the casting machine and stretched in the direction of film line by the longitudinal stretching machine before finally being stretched in the direction of film width by the transverse stretching machine. After going through the stretching process, the polymer is subjected to surface treatment, etc. in the take-off unit before being wound up in the winder.

In order to meet with the customer’s need of higher productivity, MHI has developed mass producing machine by improving the width and speed of biaxially oriented film manufacturing plant, paying consideration to the operability, maintainability and so on. MHI has developed new machines one after another. The operating speed on commercial production of the latest MHI biaxially oriented film manufacturing plant is shown in Fig. 2. With the performance of the component machines of the above-mentioned plant improved, a world-top operating speed on commercial production level (width 8.3 m x speed 450 m/min) has been achieved.

This paper describes the new structure of the casting machine, the main component of the biaxially oriented film manufacturing plant, in terms of the high performance and improved operability and maintainability.

2. Need for casting machine development

The casting machine for biaxially oriented film manufacturing plant is shown in Fig. 3. The casting machine

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**Fig. 1** Production process of biaxially oriented film manufacturing plant
The molten polymer extruded from the die is cooled to solidification by casting machine before being stretched by longitudinal and transverse stretching machines and wound up.
the cooling roll with smaller diameter and needing less space in addition to the improvement in operability at the start-up (particularly at the threading) was earnestly demanded. In order to meet with such demand or need, MHI have developed a new structure to improve efficiency (by reducing the roll diameter) and maintainability of the cooling roll. The structure and performance of the high-efficiency cooling roll are described below.

3. Structure of high-efficiency cooling roll

Fig. 5 shows the structure of the new type cooling roll compared with the conventional type. In the case of conventional cooling roll, the cooling water is led into the spiral rectangular channel installed inside the external cylinder, with the external cylinder designed independent of the cooling channel, causing the water pressure to apply throughout the inner surface of the external cylinder. This causes the roll diameter to become large and eventually the external cylinder had to be thick in order to secure sufficient strength, leading consequently to the deterioration of the heat transfer coefficient.

In the new type cooling roll, the straight circular channel is embedded in the external cylinder. The solid (integral) structure of the external cylinder and the cooling channel ensures sufficient strength and, in addition, improves the cooling efficiency through proximity of the cooling channel and the roll surface. Features are described below.

4. Features of high-efficiency cooling roll

4.1 Strength characteristics

Supposing the water pressure inside the cooling channel to be 0.5 MPa, the results of roll deformation analysis due to roll diameter and water pressure for conventional and new type cooling rolls are summed up in Fig. 6, with the figures in the parentheses indicating the external cylinder thickness ratio of each roll diameter against...
the external cylinder thickness of the φ 1000 mm roll diameter of the conventional cooling roll. The figure also shows the analytical examples of the external cylinder deformation both for conventional type (roll diameter: φ 2 600 mm) and new type (roll diameter: φ 2 000 mm). In the conventional type, the independent structure of external cylinder and cooling channel causes the water pressure to apply throughout the entire inner surface of the external cylinder restrained by the side plate, resulting in convex deformation to occur at the center against the roll edge section. This causes the roll diameter to increase, so that the deformation has to be suppressed by making the external cylinder thicker as shown in the figures in brackets.

In the case of the new type cooling roll (with roll diameter: φ 2 000 mm), the solid structure of external cylinder and cooling channel allows the external cylinder member between straight circular channel to become strong enough to suppress the deformation caused by water pressure. Consequently, the deformation in new type (φ 2 000 mm) is extremely small at 0.7 μm against the deformation 0.126 mm in conventional type (φ 2 600 mm). Thus the problem of structural strength in conventional type (needing thicker external cylinder because of the larger cooling roll diameter) has been improved and the deformation of external cylinder due

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to water pressure has been eliminated in the new type cooling roll. This has contributed to a drastic improvement in durability and reliability.

### 4.2 Heat transfer characteristics

The roll diameters and heat transfer coefficient ratio of the conventional and new type cooling rolls are summed up in Fig. 7. The heat transfer coefficient ratio indicates the ratio of the heat transfer coefficient for each roll diameter against the heat transfer coefficient for roll diameter: φ 1000 mm in a conventional type cooling roll, with the figures in the parentheses indicating the external cylinder thickness ratio for each roll diameter against the external cylinder thickness for roll diameter: φ 1000 mm in a conventional type cooling roll.

As is evident from the above example, the roll diameter in a conventional type cooling roll gets increased, causing the external cylinder to become thick. This in turn causes the heat transfer coefficient to get deteriorated as shown in Fig. 7. The external cylinder for roll diameter: φ 2600 mm becomes 3 times thicker than for roll diameter: φ 1000 mm, causing the heat transfer coefficient to reduce to 2/3.

In the case of new type cooling roll, the distance between cooling channel and roll surface can be kept constant, ensuring high heat transfer coefficient, irrespective of the roll diameter size. The figure shows the test results for roll diameters: φ 1000 mm and φ 2000 mm of the new type cooling roll, indicating the obtained heat transfer coefficient to be equivalent to the heat transfer coefficient for the roll diameter φ 1000 mm of a conventional type. It should be noted here that in the case of the new structure applying straight circular channel it is important to carry out uniform cooling of sheets in the roll circumferential direction (between circular channels). In the above-mentioned figures an example of non-steady heat conduction analysis of the sheet and cooling roll in the new type cooling roll is shown. As is evident in the figure, the roll surface temperature and sheet temperature in the new type roll are kept uniform in the roll circumferential direction (between circular channels) through optimization of the shape and arrangement of straight circular channels.

### 4.3 Maintainability

The external cylinder and side plate of a conventional type cooling roll are of welded structure, making it necessary to clean off the scale, etc. adhered to the cooling channel through chemical cleaning, which calls for complicated handling and long-term stoppage of the line. Further, the cleanliness degree cannot be confirmed after the cleaning, so that the improvement in maintainability of cooling roll has been a long demanded need.

The photo in Fig. 8 shows the appearance of the new-type high-efficiency cooling roll (with roll diameter: φ 1000 mm), while Fig. 9 shows the maintenance structure of the new type. The side plate is equipped with detachable plugs corresponding to the straight circular channels. As shown in Fig. 9, these plugs can be removed at the maintenance for cleaning by brush and the cleanliness degree after the cleaning can also be easily confirmed. With the adoption of straight circular channels, the new-type cooling roll allows cleaning of the cooling channels, leading to drastic improvement in maintainability.

### 5. Up-to-date specifications for casting machine

The specifications for casting machine applying the high-efficiency cooling roll currently in operation are

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*Note: Figures in the parentheses indicate the external cylinder thickness ratio for each roll diameter against the external cylinder thickness for roll diameter φ 1000 mm in a conventional type cooling roll.*
given in Table 1. The latest wide and high-speed line (width 8.3 m x speed 450 m/min) applies the high-efficiency cooling roll with heat transfer coefficient 1.5 times higher than that of the conventional type, and has the cooling roll diameter reduced from $\phi 2600$ mm to $\phi 2000$ mm, needing less space. This has also contributed to reducing roll diameter and the size of the whole machine and to improving the operability at the start-up (threading).

6. Conclusion

Summed up below is the casting machine, a major component of the biaxially oriented film manufacturing plant.

(1) A high-efficiency cooling roll with new structure and equipped with straight circular channel has been developed to take the place of the conventional cooling roll equipped with spiral rectangular channel.

(2) The newly developed high-efficiency cooling roll eliminates the external cylinder deformation caused by water pressure in the conventional cooling roll, with the reliability in terms of durability drastically improved.

(3) The high-efficiency cooling roll (with 1.5 times higher heat transfer coefficient) reduces the cooling roll diameter of a 450 m/min-class machine from conventional $\phi 2600$ mm to $\phi 2000$ mm and needs less space. Further, the downsizing of the machine contributes to the improvement in operability at the start-up.

(4) The adoption of straight circular channel enables the cleaning of the cooling channel, leading to drastic improvement in maintainability.

In addition to the newly developed casting machine introduced in this paper, MHI is determined to develop machines to meet with the customers' needs for improvements in production of the biaxially oriented film manufacturing plant, in operability and maintainability.

References

(1) Tsutsui, Y. et al., Study on Biaxially Oriented Film Forming Technique, Mitsubishi Heavy Industries Technical Review Vol.23 No.2 (1986) pp.186-190


<table>
<thead>
<tr>
<th>Table 1 Specifications for new type casting machine</th>
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<tbody>
<tr>
<td>For biaxially oriented film manufacturing plant (width 8.3 m x speed 450 m/min)</td>
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</tr>
<tr>
<td>Polymer</td>
<td>Polypropylene</td>
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<tr>
<td>Cooling capacity</td>
<td>max. 5000 kg/h</td>
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<tr>
<td>Sheet thickness</td>
<td>0.6 to 3.0 mm</td>
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<tr>
<td>Machine speed</td>
<td>max. 110 m/min</td>
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<tr>
<td>Cooling roll diameter</td>
<td>$\phi 2000$ mm ($\phi 2600$ mm)</td>
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<tr>
<td>Cooling roll width</td>
<td>1500 mm</td>
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</table>

Figure in the parenthesis is for conventional type roll diameter.