KAWASAKI STEEL TECHNICAL REPORT
No.15 (October 1986)

New Type Stelmor Equipment of Wire Rod and Bar Mill

Yoshiyuki Hanada, Kiyohiro Ueno, Akio Noda, Hidenori Kondoh, Toshio Sakamoto, Kimio Mine

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When the Stelmor equipment was introduced to the new wire rod and bar mill at Mizushima Works, examination was made for improving the uniform cooling characteristics of the ring-shaped pile of wire rods on the conveyer. From the basic test, it was found that the cooling rate was able to be obtained from the wind velocity distribution, and an optimum wind velocity distribution existed. Also from the test using a simulator, characteristics of the damper and deflector were clarified, and it has become possible to determine the specifications of the nozzle and blower, which can be controlled depending upon requirements for uniform cooling and product quality. The Stelmor unit to which the above-mentioned new functions have been added has features that damper and deflector operations are connected to the process computer and DDC and can be set according to the required quality of wire rods. Through the use of this improved Stelmor equipment, the scatter of tensile strength of wire rods has been reduced from 1.6 to 0.9 kgf/mm^2.

1 Introduction

At Mizushima Works of Kawasaki Steel, a new wire rod mill was constructed in a new yard next to the existing bar mill and began operation in September 1984. In this new mill, the old bar mill was remodeled into a roughing mill and an intermediate mill for wire rod rolling. The aims of the construction were improvements of wire rod quality and yield and reduction of production cost.

The Stelmor equipment installed in the mill is very important in determining the quality of wire rod; this equipment must uniformly cool the hoop wires shaped by the laying head, at a velocity appropriate to the desired material qualities. By realizing this function, it is possible to produce wire rods of uniform strength.

The overlapping of hoop wire rod is different at the center and edge on cooling conveyer, so it is necessary to optimize wind velocity distribution in order to ensure uniform cooling on the hoop wire. Therefore, a new type of Stelmor equipment has been developed to control wind velocity and direction in accordance with wire rod size and type of material.

This report describes the results of basic tests as well as those obtained with a simulator of actual size and with the actual Stelmor equipment.

2 Features and Problems in Stelmor Processing Equipment

With Stelmor equipment, as shown in **Fig. 1**, hoop wire passing through the water cooling zones at the exit side of the finishing mill and shaped by the laying head must be cooled uniformly at a velocity appropriate to the material.[1)]

As shown in **Fig. 2**, the hoop wire is not uniform in the unit length weight in the direction normal to the pass; therefore, different wind velocities are necessary at the ring center and edges to ensure uniform cooling of

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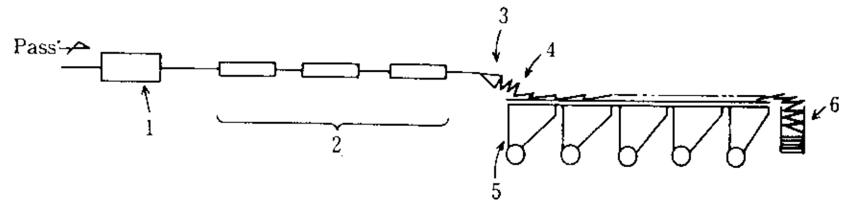


1. Finishing mill
2. Water cooling zones
3. Laying head
4. Hoop wire
5. Blowers (forced air cooling)
6. Reforming tub

Fig. 1 Equipment of Stelmor line

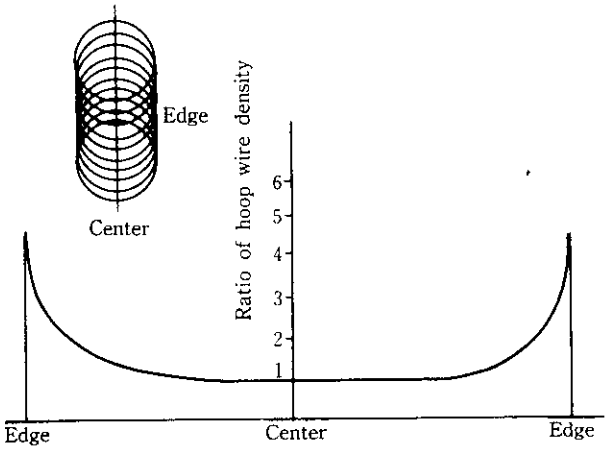


Fig. 2 Change in hoop wire density in the edge direction

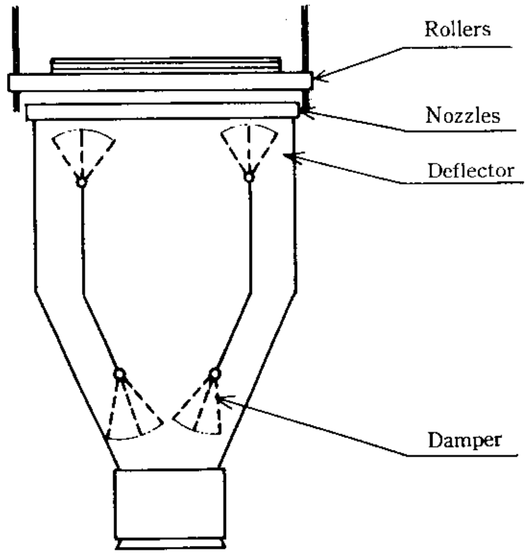


Fig. 3 New Stelmor conveyer

the wire.[2)] In this plan, the new type Stelmor equipment shown in **Fig. 3** was adopted, in which the wind velocity and direction at the center and edges can be altered in response to the size and material of the hoop wire.

The features of this equipment are as follows:

(1) Wind velocity distribution can be varied by changing the chamber pressure at the center and edges using dampers.

(2) Wind direction at the ring edges can be changed by deflectors.

Accordingly, it is possible to control cooling to appropriate rates for the size and type of material.

This new equipment is different from conventional equipment in which cooling capacity for the ring center and edges varies according to nozzle area which is fixed. Therefore, the effects of the method of operation, quality changes attendant on wind velocity distribution, and other factors were not clear, and it was necessary to study the new equipment, beginning with the conditions for uniform cooling of hoop wire. The points of investigation toward the solution of the problems mentioned above are as follows:

(1) Relation between wind velocity and distribution and cooling rate

(2) Optimum wind velocity distribution appropriate to the ring center and edge of the hoop wire pile

(3) Damper characteristics

(4) Deflector characteristics

3 Results of Preliminary Tests

Preliminary tests were performed with the apparatus shown in **Fig. 4** and two types of test pieces, both 200 mm long, one 5.5 mmϕ (SWRH62B) and other 11 mmϕ (S45C), in order to examine material behavior under forced air cooling and to determine nozzle specifications.

3.1 Test Procedure

With this experimental apparatus, each test piece was heated to 900°C and then cooled to confirm that the cooling rate agreed with the heat transfer theory. Also, to confirm estimates of the cooling rate in the actual Stelmor, test pieces were moved cyclically and cooled using several wind velocity distributions.

Furthermore, cooling characteristics were examined using bundled test pieces to simulate ring edge piling of hoop wire in the actual Stelmor conveyer (**Fig. 5**). Ring edge position differs according to position in the pass, as shown in **Fig. 6**. Therefore, considering cross points of ring edges (1, 2, 3, ...), the mean number of piled wires was calculated assuming that the dimension X is equal to or less than the wire diameter d, and was determined to be 2~4 when ring pitch P is in the range 30~120 mm. **Photo 1** shows piles of edges corresponding to P= 47 and 120 mm in the actual Stelmor.

To obtain the basic data for determining nozzle specifications, nozzles 7, 14, 20 and 25 mm wide were used, arranged in the pass direction either between or under the rollers (**Fig. 7**).

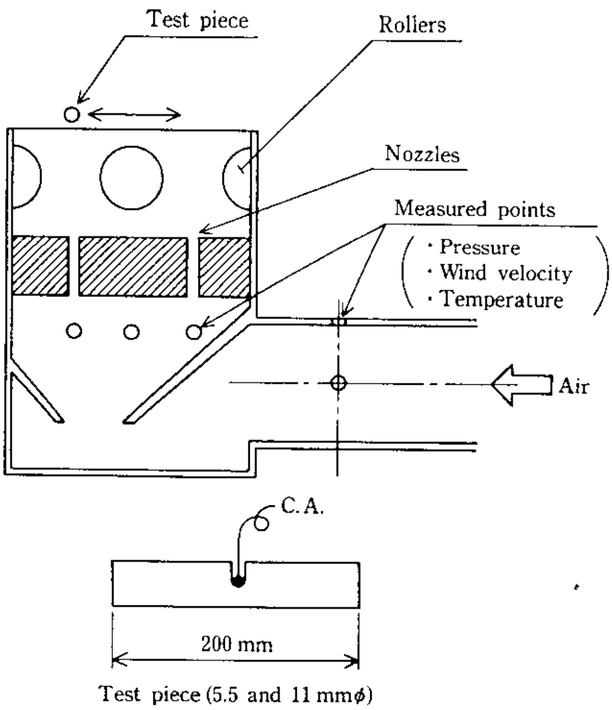


Fig. 4 Experimental apparatus for air cooling

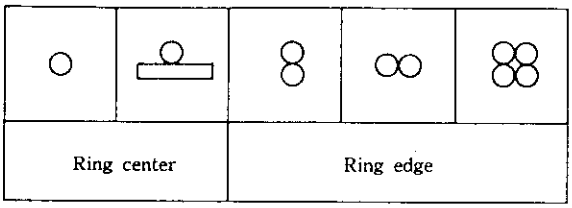


Fig. 5 Test pieces

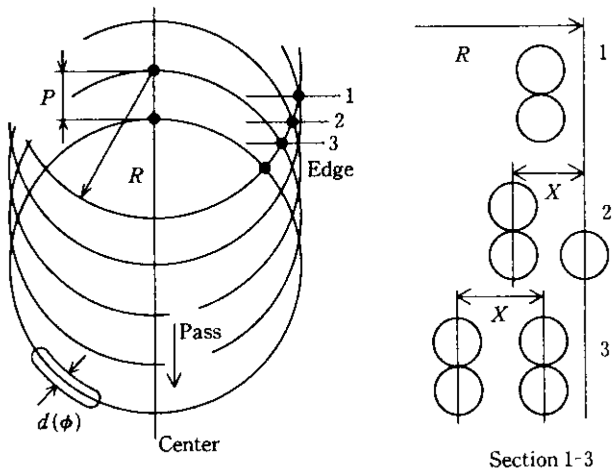


Fig. 6 Model of ring edge

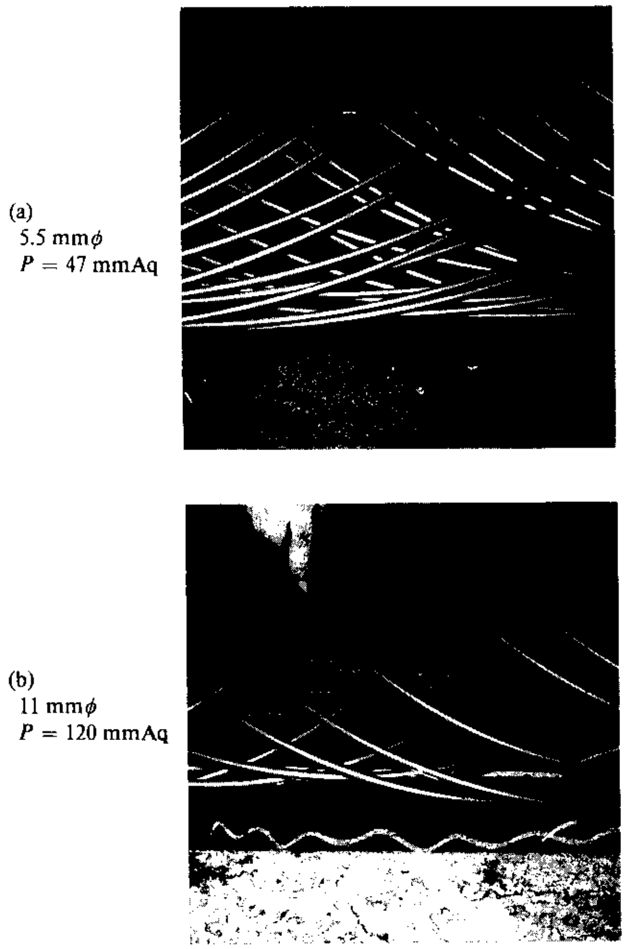


Photo 1 Example of wire overlap at ring edge

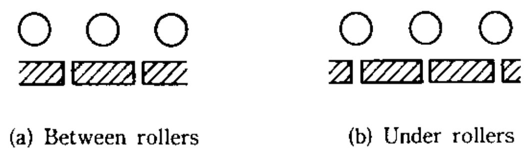


Fig. 7 Position of nozzles

3.2 Results

The results of the preliminary tests are as follows:

(1) **Figure 8** compares calculated and actual cooling rates[3] for a single wire. These velocities agree well at a radiation factor of 0.7.

(2) The single wire cooling rate under a given wind velocity distribution can be estimated from the positional integration of wind velocity, as shown in **Table 1**. Therefore, the cooling rate of the single wire area of a hoop wire can be estimated from the wind velocity distribution in the actual Stelmor.

(3) As shown in **Fig. 9**, the cooling rates at the two- and four-wire piled areas reduce to 80% and 65% that of single wire, respectively. Wire size does not affect cooling rate so much as wire piling.

(4) **Figure 10** shows cooling rate results when nozzle width is varied. Cooling rate depends only on flow quantity and not on nozzle width. Therefore, cooling rate can be determined by using flow quantity as the primary parameter and considering blower capacity and control methods.

(5) As shown in **Table 2**, cooling rates for nozzles arranged between and under rollers are about the same. However, as shown in **Fig. 11**, wind velocity distribution is more stable in the under-roller position than in the between-roller position. Therefore, for uniform cooling, it is desirable to arrange the nozzles under the rollers.

Based on the above results, the ratio of ring center (single wire part) wind velocity to edge wind velocity

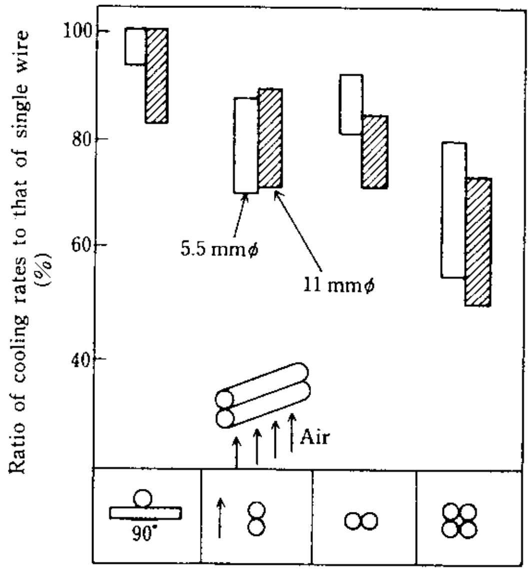


Fig. 9 Effect of wire overlap on cooling rate

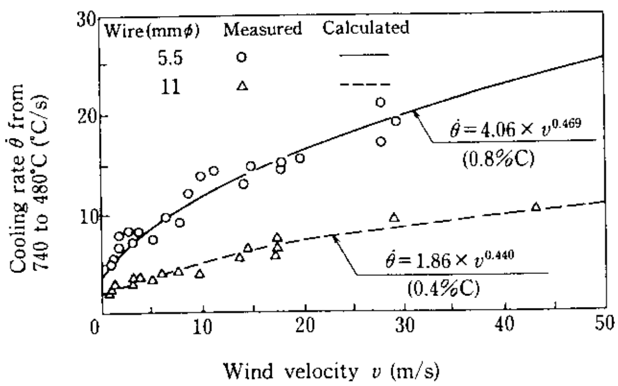


Fig. 8 Comparison of measured and calculated cooling rates

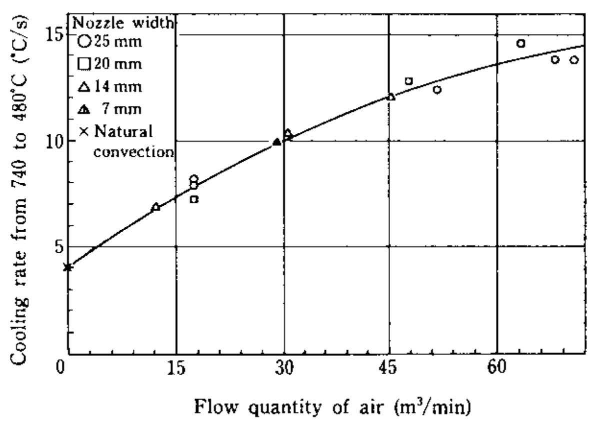


Fig. 10 Influence of nozzle width on cooling rate of 5.5 mmϕ wire calculated from wind velocity distribution

Table 1 Comparison of cooling rate calculated from wind velocity distribution with measured cooling rate

Pressure (mmAq)	Cooling rate (°C/S)	
	Measured, $\dot{\theta}$	Calculated, $\dot{\theta}_0$
20	10.5	9.3
90	14.3	14.6
150	16.6	16.7

Table 2 Influence of nozzle location on cooling rate of wire (nozzle width 25 mm) (°C/s)

Static pressure (mmAq) \ Nozzle location	Between Rollers	Under Rollers
15	8.2	7.9
150	13.8	13.8

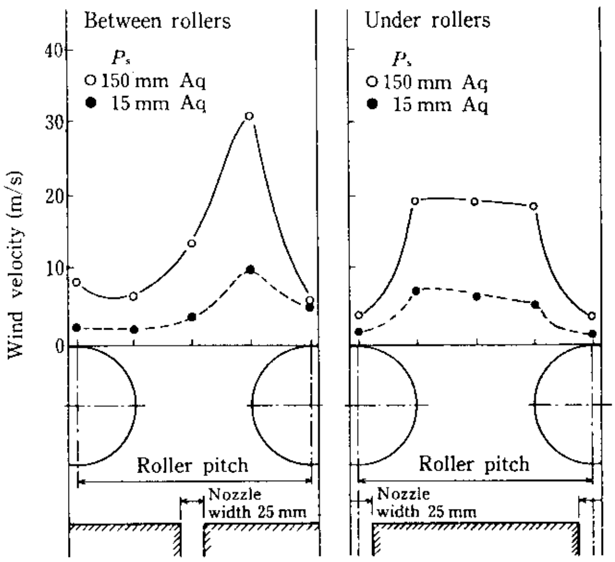


Fig. 11 Wind velocity distributions at nozzle between rollers and nozzle under rollers

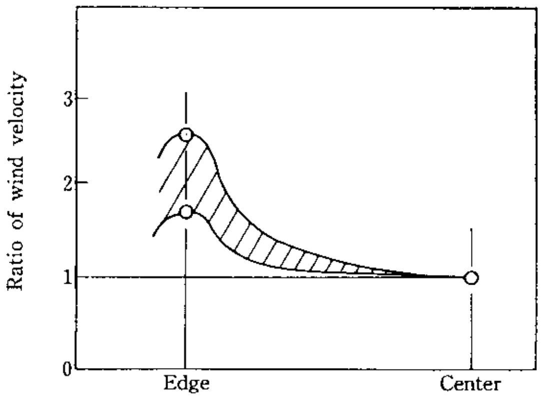


Fig. 12 Optimum range of wind velocity at ring edge

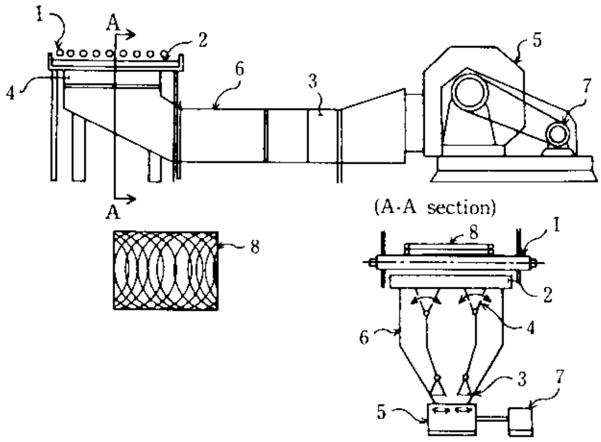
was calculated. As shown in **Fig. 12**, this ratio is in the range 1.7~2.5, where it is considered that optimum wind velocity distribution exists.[4)]

For stable cooling, it is preferable to arrange the nozzles under the rollers. It is considered feasible to determine nozzle width on the basis of required cooling capacity, blower capacity, and control method in the actual Stelmor.

4 Simulator Experiments and Discussion

From preliminary tests, the ranges of optimum wind distributions and nozzle design requirements were obtained. However, it was also necessary to obtain data corresponding to actual hoop wire, and information on the characteristics of dampers and deflectors.

For this reason, as shown in **Fig. 13**, a simulator was



1. Rollers	5. Blower
2. Nozzles	6. Duct
3. Damper	7. Motor
4. Deflector	8. Test piece

Fig. 13 Simulator of new Stelmor line

constructed in ratios to the actual Stelmor of 1/1 in width and 1/3 in the pass direction, and tests were performed.

4.1 Test Procedure

Since it was clear from the preliminary test that cooling rate could be estimated from wind velocity distribution, the characteristics of dampers and deflectors were investigated using the data on wind distribution. For heating and cooling tests, representative sample portions of the center and edge of the test piece shown in Fig. 13 were taken and placed in the simulator (**Photo 2**). For some specimens, tensile tests were performed.

4.2 Results and Discussion

Results were as follows:

(1) Cooling rates were estimated from Eq. (1) using wind velocity obtained in the preliminary tests. The results agreed well with measurements of actual hoop wires (**Fig. 14**).

$$\dot{\theta} = a \times 4.06 \times v^{0.469} \quad \cdots\cdots(1)$$

Where, $\dot{\theta}$: Cooling rate (°C/s) of 5.5 mmϕ specimen at 740 – 480°C
v: Wind velocity (m/s)
a: Overlap density coefficient (See Fig. 9)
1.0 – 0.8 at the center
1.0 – 0.65 at the edge

This indicates that the cooling of hoop wire is not peculiar phenomenon, but can be explained by the general theory of forced convection.

(2) **Figure 15** shows the effect of dampers on cooling rate. When the damper opening is 100% (edge side closed), the cooling rate at the edges is reduced. On the contrary, at 0% (center closed), the cooling rate

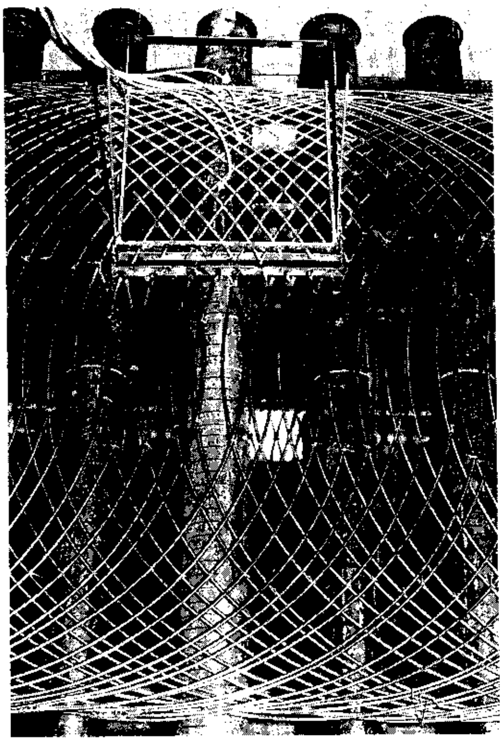


Photo 2 Test piece at ring edge

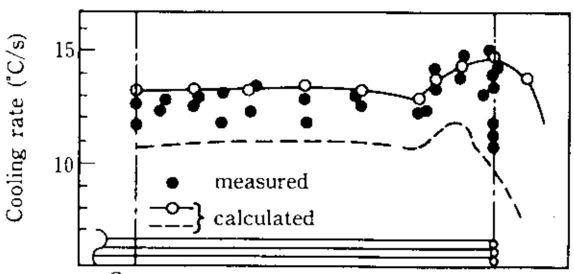


Fig. 14 Cooling rate with simulator (measured and calculated)

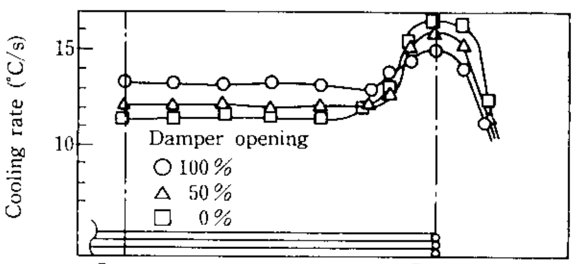


Fig. 15 Influence of damper opening on cooling rate

at the edges increases. Therefore, it is clear that the ratio of cooling rates at the center and edge can be varied over a wide range. From these results, it is

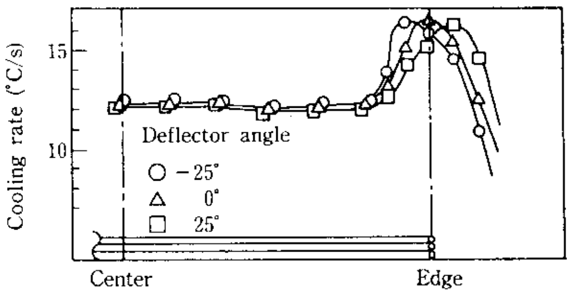


Fig. 16 Influence of deflector angle on cooling rate

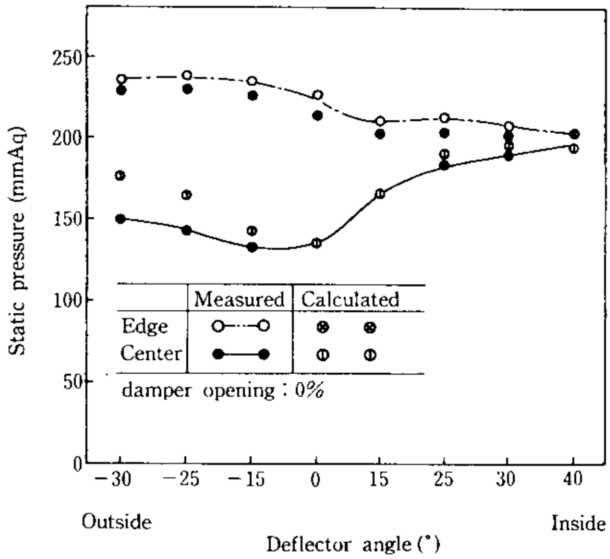


Fig. 17 Static pressure characteristics of damper

obvious that for any pile of hoop wire the optimum wind velocity distribution can be determined, contributing to uniform wire rod production.

(3) **Figure 16** shows the influence of deflectors on wind direction. It is clear that peak wind velocity distribution can be adjusted in the transverse direction by changing the directions of the deflectors. Combining this result with compensation for ring diameter and the above results (2), it becomes possible to also adjust the boundary position between the center and edge, contributing to uniform wire rod production.[5]

(4) **Figure 17** shows an example of duct pressure variation for relative changes in damper and deflector position. Pressure can also be estimated from the degree of duct opening between the center and edge, damper and deflector openings, and nozzle area. In the model shown in **Fig. 18**, the angle of equilibrium for center and edge duct pressures is θ_n. When the damper is set at a smaller angle than θ_n, center duct pressure P_c is determined by the following relations.

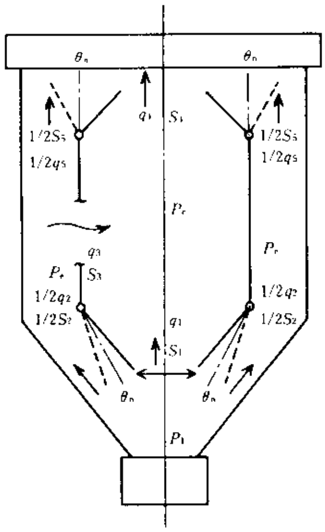


Fig. 18 Model of damper and deflector

$$P_e = P_1$$

$$q_1 = C_1S_1\sqrt{\frac{2g(P_1 - P_c)}{\gamma}}$$

$$q_3 = C_3S_3\sqrt{\frac{2g(P_e - P_c)}{\gamma}}$$

$$q_4 = C_4S_4\sqrt{\frac{2gP_c}{\gamma}}$$

$$q_4 = q_1 + q_3$$

P_e, P_c, $P_1 \sim P_5$: Pressures
$C_1 \sim C_5$: Flow rate coefficients
$S_1 \sim S_5$: Flow path areas
$q_1 \sim q_5$: Flow rates
g: Gravitational acceleration
γ: Specific gravity

Thus, center duct pressure P_c can be calculated from Eq. (2) below, and at larger angles than θ_n, edge duct pressure P_e can similarly be calculated from Eq. (3)

$$P_c = P_1 \Big/ \left[1 + \left(\frac{C_4S_4}{C_1S_1 + C_3S_3}\right)^2\right] \cdots\cdots(2)$$

$$P_e = P_1 \Big/ \left[1 + \left(\frac{C_5S_5}{C_2S_2 + C_3S_3}\right)^2\right] \cdots\cdots(3)$$

From the results of these calculations, it is possible to estimate nozzle flow rate. Also, as described earlier, wind velocity distribution can be adjusted, so that it is possible to set the dampers and deflectors as appropriate for uniform cooling of hoop wire.

(5) **Figure 19** shows the results of tensile tests of the specimens used in this investigation. These results show examples of control appropriate to cases where uniform product quality and lower limit values must be guaranteed.

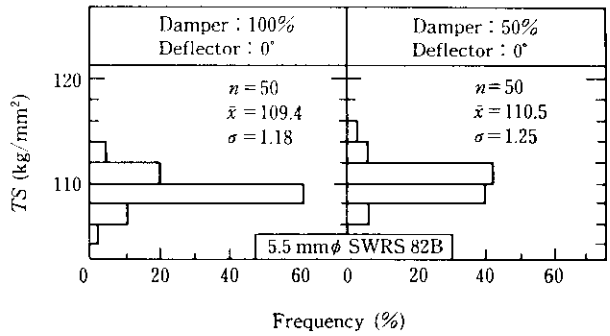


Fig. 19 Tensile strength with simulator

From the results described above, the characteristics of the dampers and deflectors are clear, and, therefore, by their control, it becomes possible not only to obtain material of uniform quality but also to control the manufacture of wire rods to meet prescribed quality specifications.

5 Actual Stelmor Equipment Design

In the design of the new Stelmor equipment, nozzle and blower specifications and control conditions were

Photo 3 New Stelmor conveyer

Table 3 Specifications of the new Stelmor line

Type	Roller conveyer ×8 zones
Blower	250 mmAq × 1 100 m³/min × 11
Control	AC-VVVF
Maker	SHI-Morgan
Unit	1

determined by considering the results of the preliminary test and simulator experiments described above.

The actual Stelmor equipment, shown in **Photo 3**, possesses the cooling characteristics expected from the test results. **Table 3** shows the main specifications of this equipment. In addition, the following features are provided:

(1) The dampers and deflectors can be adjusted by process computer and DDC according to the quality requirements for wire rods.

(2) A heat insulating cover is attached for production of materials for slow cooling.

6 Results of Rolling

Based on the test results described above, the actual Stelmor was designed, and performance trials started at the beginning of August 1984. Wire rod with low strength scatter was obtained from the first as expected, tests were completed without difficulties, and commercial operation began in September 1984.[6]

Figure 20 shows results of material tests with the former equipment and the new wire rod rolling mill. The scatter of tensile strength within a single ring has been reduced from about 1.6 to about 0.9 kgf/mm^2. Thus, it can be said that the effectiveness of the new Stelmor equipment in material production is great.

7 Conclusions

As stated above, when the Stelmor equipment was introduced in the new wire and bar mill at the Mizushima Works, an investigation was made into means of improving the uniform cooling characteristics of the ring-shaped configuration of wire rod on the conveyor. From the preliminary test, it was found to be possible to control the cooling rate through wind velocity distribution.

An optimum wind velocity distribution was also discovered. From simulator tests, characteristics of the dampers and deflectors were clarified, and it has also become possible to determine the specifications of the nozzles and blowers; these components, moreover, can be controlled in response to requirements for uniform cooling and product quality.

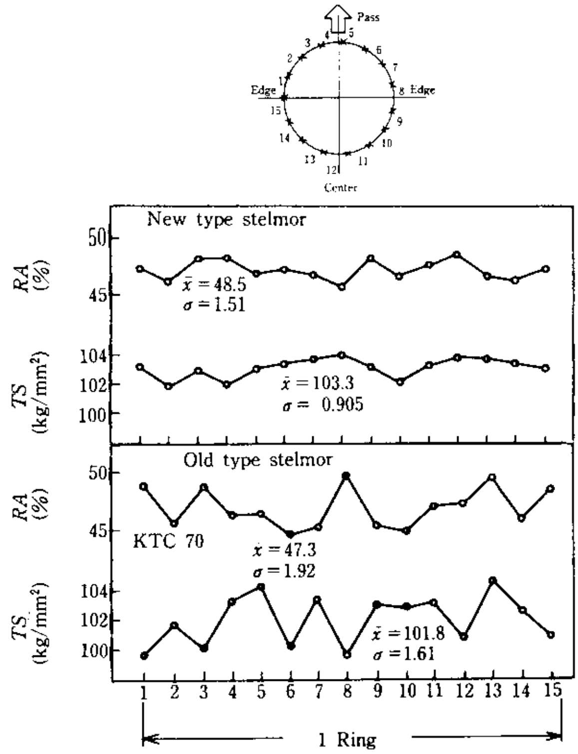


Fig. 20 Tensile strength and reduction of area of wire produced with new and old Stelmor

The Stelmor equipment, to which the new functions mentioned above have been added, features damper and deflector operations which can be linked to a process computer and DDC and controlled according to product quality requirements. Through the use of this improved Stelmor equipment, the scatter of tensile strength of wire rods has been reduced from 1.6 to 0.9 kgf/mm^2.

The next undertaking is an establishment of methods for the controlled production of wire rods of any specified quality by effective use of dampers and deflectors with the characteristics stated above.

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