Development of Belt-Type Single Facer

Yoshiaki Maruyama\textsuperscript{1}
Hiroshi Suzumura\textsuperscript{1}
Masahiro Yamaguchi\textsuperscript{1}
Yukuharu Seki\textsuperscript{2}

With the increasing demand for higher productivity and quality, medium ruptures and the rise in noise have recently become serious concerns in the corrugating process of a conventional single facer. In order to develop a new type of single facer which uses a running belt instead of the pressure roll used in conventional units, investigations have been conducted on the rationalization of the adhesive conditions, the prevention of the unstable running and deformation of the belt and practical measures to reduce the noise level. With the belt type single facer, low noise of 95 dB(A) at the high production speed of 400 m/min has been successfully achieved without press marks.

1. Introduction

A single facer is a machine that produces single faced corrugated boards from a corrugating medium and liner web during the first production process of a corrugating machine that produces corrugated board sheets as shown in Fig. 1 (a).

Mitsubishi Heavy Industries, Ltd. (MHI) developed the world’s first fingerless single facer in 1978. Since then, MHI has developed a single facer that allows easy changing of corrugating rolls and that has good maintainability and operability in turn in line with the varied needs of domestic and foreign customers. More than 400 units of single facers have been delivered to various countries around the world to date.

However, current machines still have several shortcomings requiring improvements in productivity, sheet quality, working environment, operability and maintainability. MHI has developed a new type of single facer with a completely new concept that employs an adhesive with a pressing belt instead of a pressure roll as a break through method to satisfy the requirements mentioned above. This paper reports on the purpose of development and the features of this new type of single facer as well as on the outline of the basic research done

\*1 Hiroshima Research & Development Center, Technical Headquarters
\*2 Mihara Machinery Works

\textsuperscript{1} Mitsubishi Heavy Industries, Ltd.
Technical Review Vol.31 No.3 (Oct, 1994)

\textbf{Fig. 1 Schematic view of corrugating machine and layout of single facer}

The single facer is a machine which produces single faced corrugated boards from corrugating medium and liner web. The conventional single facer is of a pressure-roll type while the new-type single facer is of a belt-press type.
in developing it.

2. Belt-type single facer

2.1 Purpose of development

The conventional pressure-roll type single facer, shown in Fig. 1 (b), produces single faced corrugated boards in such a way that the corrugating medium corrugated between the upper and lower corrugating rolls is glued and adheres instantaneously to the liner due to the pressing of the pressure roll. Since the pressure roll must press the corrugating medium under high pressure because the pressing time is very short, resonance occurs between the lower corrugating roll and the pressure roll at high speed which causes liner rupture and high levels of noise.

The new-type single facer has been developed for the purpose of reducing noise and vibration and in order to produce corrugated boards without any press marks (dents on the liner caused by the press under high pressure). To achieve this, a new type of belt-press shown in Fig. 1 (c) has been adopted, and the adhesion time of the corrugating medium and liner has been sufficiently lengthened to allow the pressure roll to press under low pressure.

2.2 Features of the belt-press type single facer

Table 1 compares the conventional and new-type single facers. The new-type single facer has the following features.

(1) High quality

Sheets without any press marks can be produced even from low-grade webs and it makes it possible to enhance the strength of sheets and boxes. It also makes printing and the adhesion of preprints on the bottom liner possible.

(2) Environmental suitability

Mechanical noise is as low as 95 dB(A) at 400 m/min, 88 dB(A) at 250 m/min and 84 dB(A) at 200 m/min, and further, sounds soft. Vibration is also small.

(3) Operability

It is not necessary to adjust loading pressure and clearance between the corrugating roll and pressure roll. Liner ruptures and inferior adhesion do not occur.

3. Establishment of suitable adhesive conditions

3.1 Technical concerns

Since the pressing method of the new-type single facer is different from that of the conventional method, it is necessary to establish suitable adhesive conditions in order to obtain an adhesive strength equal to that of the conventional type. However, theory that includes loading pressure, starch temperature and an adhesion time has not been established up to now. Therefore, quantifying the adhesion time to obtain equal adhesive strength in cases of lower loading pressure is a technical problem, using loading pressure, starch temperature, and time of adhesion as parameters. A method of estimating suitable adhesive conditions through fundamental tests and results of the verification test on an actual machine are shown below.

3.2 Estimation of suitable adhesive conditions through fundamental tests

Fig. 2 shows an adhesive strength measuring device developed for fundamental tests. This device fits 5 cm square samples each of corrugating medium and liner on jigs and measures initial adhesive strength after gluing, sticking and pressing them. Loading pressure, starch temperature and adhesion time can be changed as parameters.

Adhesive strength was measured on this device by changing the above-mentioned parameters. As a result, it was found that adhesive strength $F$ can be expressed in an exponential form against the adhesion time $t$ in a range of $t$ of 2 s or less under the condition of the same loading pressure. It was also found that the relation between the measured adhesive strength and mean temperature $T_o$ can be approximately shown by a straight line when plotted based on Arrhenius' equation (1). The mean temperature $T_o$ is obtained by integrating temperature curve measured with a fine wire thermocouple fitted onto the glue unit in a range of from zero to 2 s.

The following experimental equation was obtained from the above using adhesive strength, starch temperature and adhesion time as parameters.

$$F = A_1(P + A_2) \left[ \exp \left( -\frac{E}{RT_o} \right) \right] t^n \quad (1)$$

Where,

$A_1, A_2$: Constant (–)

$E$: Activation energy (J/g-mol)

$exp$: Exponential function

$F$: Adhesive strength (N/m$^2$)

$P$: Loading pressure (N/m$^2$)

$R$: Gas constant (=8.314 J/g-mol · K)

$T_o$: Average starch temperature of adhesive part (K)

Table 1 Comparison of conventional and new-type single facers

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional machine (pressure-roll type)</th>
<th>New-type machine (belt-press type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. machine speed</td>
<td>300 m/min</td>
<td>400 m/min</td>
</tr>
<tr>
<td>Max. machine width</td>
<td>2 500 mm</td>
<td>2 500 mm</td>
</tr>
<tr>
<td>Noise level</td>
<td>118 dB(A)/300m/min</td>
<td>95 dB(A)/400m/min</td>
</tr>
<tr>
<td></td>
<td>110 dB(A)/200 m/min</td>
<td>88 dB(A)/250 m/min</td>
</tr>
<tr>
<td></td>
<td>84 dB(A)/200 m/min</td>
<td>84 dB(A)/200 m/min</td>
</tr>
<tr>
<td>Sheet quality</td>
<td>Press marks present</td>
<td>No press marks</td>
</tr>
</tbody>
</table>

Fig. 2 Testing device for adhesive strength

A testing device for measuring adhesive strength that simulates actual machine conditions.
$n$: Exponent of time term ($-$) $n = f(P)$

$t$: Adhesion time (s)

When using a loading pressure $P$ corresponding to the linear pressure of the conventional single facer, adhesion time $t$ and starch temperature $T_r$, adhesive strength $F_i$ can be obtained from Equation (1). Next, the relation between the loading pressure and adhesion time as shown in Fig. 3 can be obtained from Equation (1) under the conditions of the same adhesive strength $F_i$ and starch temperature $T_r$. Various operating conditions for the new-type single facer can be obtained from this necessary adhesive strength line.

3.3 Verification tests on an actual single facer

Pilot tests were conducted to verify the adequacy of the experimental equation after determining the loading conditions for the belt that satisfy suitable adhesive conditions as mentioned above. It was found that the adhesive strength of products made using the new-type single facer measured with a pin attachment tester is greater than that of products made using a conventional single facer. The pin attachment tester evaluates the usual resistance of adhering parts between the flute tips of the corrugating medium and liner.

Thus, it has become possible to determine design conditions for the new-type single facer and operating conditions for it by using the aforementioned equation to determine suitable adhesive conditions.

4. Control of belt walking and deformation

4.1 Technical concerns

In the new-type single facer, a endless belt runs at high speed on two belt rolls and the upper corrugating roll. Technical concerns are shown in Fig. 4 for stable running of the belt. The crown and the deflection of the roll induce forward or backward deformation in the center of the belt width. In addition, the lateral walking of the belt can occur when rolls are not parallel to each other due to manufacture errors of the belt or installation errors of the rolls. When such deformations and/or walking of the belt become noticeable, unstable running and/or inferior adhesion can occur. It is therefore important for the stable running of the belt to prevent the in-plane deformation and lateral walking of the belt.

The theoretical method of analyzing the belt walking and deformation phenomena and results of verification tests on an existing machine are described below.

4.2 Belt walking and deformation theory

Walking and deformation states of the belt are determined by the distribution of the direction and magnitude of the frictional force that the belt experiences while running on the belt roll. Upper corrugating roll Belt roll

![Fig. 3 Relation between pressure and adhesion time](image)

Loading pressure and adhesion time can be determined from this relation for the new-type single facer.

![Fig. 4 Technical concerns for stable running and deformation of belt](image)

Forward or backward deformation, shrinkage in the cross direction, and walking must be prevented for the stable running of the belt.

Mitsubishi Heavy Industries, Ltd.
rolls. The deformation of the belt and rolls are shown by the curved lattice and axis Lr in Fig. 5 (a). Frictional force $F$ acts on the belt in the direction of a differential vector between the roll surface velocity $V_r$ and belt velocity $V_b$ after deformation and causes in-plane deformation of the belt, while the $F_a$ component of the frictional force in the direction of the roll axis causes lateral walking of the belt. In a steady state of the belt walking, the resultant frictional force acting on the entire belt must be in a state of equilibrium (2), which requires the following equilibrium equation in the direction of the roll axis.

$$\int [\text{sgn}(V_r - V_b) \sin \theta_r - (V_r - V_b + V_b) \mu \rho dA] = 0$$

(2)

In the above equation, the symbol sgn is 1 when the value in [ ] is positive and is -1 when it is negative, $V_b$ the belt walking velocity, $\mu \rho$ (= $F$) frictional force, and $\int \cdot \cdot \cdot \cdot dA$ shows the integration of frictional force over the entire contacting surface between the belt and roll. The belt and roll speeds, $V_r$ and $V_b$, and their respective angles $\theta_r$ and $\theta_b$ are calculated using the finite element model shown in Fig. 5 (b) taking the shape of the roll and loading condition into account. Roll crown is expressed by applying thermal expansion to a rigid beam. In the numerical calculation of the belt walking velocity $V_b$, iterative calculation is needed until Eq. (2) is satisfied within an allowable tolerance, since $V_b$ depends upon the deformation of the belt.

4.3 Verification tests on an existing single facer

Verification tests were conducted using existing single facer in order to confirm the practicability of the above-mentioned theory. Fig. 6 shows the relation between the in-plane deformation and roll crown. The cross mark (×) in the figure shows the theoretical optimum amount of crown where the walking velocity becomes zero. As the result of the tests, in-plane deformation and shrinkage in the cross direction of the belt became considerably smaller and walking could be kept within allowable limits at an optimum amount of crown. For the new-type single facer, the optimum amount of crown was determined from the roll shape and loading conditions on the basis of this way of thinking.

5. Reduction of vibration and noise

5.1 Reduction of vibration

Since the pressure roll with a smooth surface is pressed against the lower corrugating roll which has an uneven surface

---

Fig. 5 Analysis model for running and deformation of belt

Theoretical analysis model for running and deformation of belt taking into account the rigidity of the belt and roll, the degree of parallelism and crown of the roll, and sliding frictional force.
in the conventional single facer, intermittent force apply to the pressure roll resulting in roll vibration and sheet rupture. On the other hand, since the number of flutes to be simultaneously pressed is large in the new-type single facer, fluctuations in pressing force accompanying the rotation of the roll naturally decrease. High speed and high quality as well as low noise mentioned below can be realized thanks to this advantage.

5.2 Reduction of noise

Noise in conventional single facers is mainly composed of noise caused by the vibration of the pressure roll and upper corrugating roll (the degree of contribution being about 70%), and flute-biting noise between corrugating rolls (the degree of contribution being about 30%). Noise of the new-type single facer, on the other hand, can be considerably reduced because the former noise disappears completely.

Fig. 7 shows the results of noise and roll vibration measurements. They are reduced from a maximum of 118 dB(A) (at 300 m/min) and 11 G<sup>−</sup> for the conventional single facer to a maximum of 95 dB(A) and 7 G<sup>−</sup> for the new-type single facer. These reductions have been realized by replacing the pressure roll pressing the lower corrugating roll with the belt. Peaks in noise and vibration also disappear. As a result, the new-type single facer realizes stable operation up to a high production speed of 400 m/min and high sheet quality.

6. Conclusion

This research was conducted for the purpose of establishing suitable adhesive conditions and studying methods of controlling the lateral walking and deformation of the belt as well as measures to reduce noise in order to develop belt-type single facers to replace conventional pressure-roll-type single facers. As a result, a low noise of 95 dB(A) at 400 m/min could be achieved and high-quality sheets without any press marks could be produced.

The first new-type single facer was delivered to the United States in November of 1992 and, as of January of 1994, a total of seven units (four in foreign countries and three in Japan) are in service under good condition. This new type of single facer can improve the productivity of the entire corrugating machine by increasing the production speed of the single facer and can improve the working environment by reducing noise. Further, it can produce high quality sheets having no press marks without performing troublesome adjustments of the loading pressure and clearance between rolls. The authors think that this new type of single facer fully meets customer demands, however, the authors intend to propose plans for further reduction in noise in the future.

References