Development of Double Medium Corrugated Fiberboard Production Machine

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There has been an increasing demand in the corrugated fiberboard industry for a new type of corrugated fiberboard with high compressive strength and high shock-absorption, accordingly a double medium corrugated fiberboard which has high and low flutes is proposed. In order to produce this new fiberboard, accurate flute position control technology is required. A double medium corrugated fiberboard production machine, which incorporates a technique to measure the position difference between the high and low flutes and a method of accurate sheet tension control, has been developed. The correct sheet tension is calculated by using the measured position difference and the extension rigidity of the paper. As a result of production tests of the newly developed machine, a maximum position difference within ±3mm has been successfully achieved at the maximum machine speed of 180 m/min, using liners from 150 g/m² to 300 g/m².

1. Introduction

Conventional corrugated fiberboard has a structure consisting of multi-layer single-faced corrugated fiberboard using single-layer corrugating medium. However, when a structure of double layer corrugating medium which has different flute height is employed, it is possible to achieve a functional corrugated fiberboard which has both shock-absorption properties not found in double faced corrugated fiberboard and a higher compressive strength than that of double wall corrugated fiberboard.

In order to produce such specific corrugated fiberboard, the flute position of two corrugating mediums having different flute heights should be adjusted so as to be mated and pasted together. However, since the single faced corrugated fiberboard having corrugating medium tends to shrink when heated and becomes elongation due to variations in tension, a suitable means is necessary to address such problems during the production process.

In this research a high precision flute position measurement technique and flute position correction technique have been devised, and the first double medium corrugated fiberboard production machine has been developed in the world. These accomplishments are reported in this paper.

2. Features of double medium corrugated fiberboard and outline of the production machine

2.1 Features of double medium corrugated fiberboard

The double medium corrugated fiberboard, as shown in Fig. 1, has a structure in which two layers consisting of low-flute and high-flute corrugating mediums of equal flute pitch and different flute heights are arranged between the linerboards.

Fig. 1 Shape of double medium corrugated fiberboard
Double medium corrugated fiberboard has a double corrugating medium of equal flute pitch and different flute heights between the linerboards.

Fig. 2 Flat compressive characteristic of double medium corrugated fiberboard
Double medium corrugated fiberboard has the characteristics of both good shock-absorption effect, which is not in the double faced corrugated fiberboard, and greater maximum compressive strength than that of double wall corrugated fiberboard.

Fig. 2 shows an example of some flat compression test results obtained for double medium corrugated fiberboard. Fig. 2 also shows the flat compressive behavior of double faced corrugated fiberboard and double wall corrugated fiberboard for comparison. Compressive load accompanied by an increase in the compressive deformation of the double medium corrugated fiberboard is equal to that of double facing corrugated fiberboard until the high-flute corrugating medium comes into contact with the low-flute corrugating medium. However, thereafter the compressive load is higher than that of double faced corrugated fiberboard, and the maximum compressive load becomes higher than those of double faced and double wall corrugated fiberboard.

As shown in Fig. 2, the flat compressive deformation

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behavior of the double medium corrugated fiberboard can be described as follows. The high-flute corrugating medium becomes trapezoidal in shape in stage ②, and the compressive load shows its first peak due to contact of the high- and low-flute corrugating mediums. Thereafter, the compressive load increases with an increase in the compressive deformation, while in stage ③ the high-flute corrugating medium becomes rectangular in shape and the low-flute corrugating medium becomes trapezoidal in shape resulting in the maximum compressive load producing a second peak. After exceeding stage ④, the compressive load decreases somewhat due to buckling of the high-flute corrugating medium. However, since the low-flute corrugating medium becomes rectangular in shape, a third peak of the compressive load is produced as shown in stage ⑤.

From the above, it can be seen that the double medium corrugated fiberboard has shock-absorption properties which are not found in double faced corrugated fiberboard and has a higher maximum compressive strength than that of double wall corrugated fiberboard. Another feature of double medium corrugated fiberboard is that it has one less liner sheet compared with double wall corrugated fiberboard.

2.2 Outline of double medium corrugated fiberboard production machine

Fig. 3 shows a schematic view of the double medium corrugated fiberboard production machine. First, single-layer medium single faced corrugated fiberboard is produced by pasting low-flute corrugating medium faced with the linerboard at a No.1 single facer. Second, the flute position difference between the low-flute corrugating medium of the single-layer medium single faced corrugated fiberboard and the high-flute corrugating medium faced is detected by a flute position measurement sensor. Sheet tension is then calculated to correct differences in the flute position by using a flute position control device. The tension of the single-layer medium single faced corrugated fiberboard is varied with an adjustment device for sheet tension. Thereafter, double medium single faced corrugated fiberboard is produced by pasting single-layer medium single faced corrugated fiberboard with high-flute corrugating medium by using a No.2 single facer. The double medium corrugated fiberboard is then produced by pasting it with the linerboard on a heating plate.

The existing facer can be used by utilizing the above production method. Double faced corrugated fiberboard and double wall corrugated fiberboard other than the double medium corrugated fiberboard can be produced by changing the sheet path.

The key point in such a production method is that the position difference between high and low flutes in the high-flute and low-flute corrugating mediums can be continuously corrected. For this purpose, a high-precision flute position control technique which includes the capability of measuring...
flute position differences and adjusting sheet tension is needed.

3. Flute position measurement device and adjustment device for sheet tension

3.1 Flute position measurement device

Fig. 4 shows the measurement principle for determining the flute position difference between high- and low-flute corrugating mediums by using the flute position measurement device. The flute pulse of the low-flute medium single faced fiberboard and the flute pulse of the high-flute corrugating medium faced are detected by the flute position measurement sensor, and the differences in both pulses are averaged at constant measurement interval in order to obtain the flute position difference \( \delta \).

3.2 Adjustment device for sheet tension

Fig. 5 shows a schematic view of the adjustment device for sheet tension. The low-flute medium single faced corrugated fiberboard is wound on the guide-roll for braking so that the flute side of the corrugating medium faces the guide-roll. The tension of the low-flute medium single faced corrugated fiberboard can be adjusted by varying the torque of the guide-roll for braking by using the brake via the driving belt.

The maximum sheet tension, \( T_{\text{MAX}} \) at the exit side of the guide-roll for braking occurs just before the sheet tension adjustment is disabled due to slippage of the low-flute medium single faced corrugated fiberboard on the guide-roll for braking. \( T_{\text{MAX}} \) is shown by the following equation.

\[
T_{\text{MAX}} = T_0 \left( \exp(\mu \theta) \right)
\]

where,

- \( T_0 \): Sheet tension at the entrance side of the guide-roll for braking
- \( \mu \): Coefficient of friction on the surface of the guide-roll for braking
- \( \theta \): Angle of contact of the single faced corrugated fiberboard on the guide-roll for braking

\( T_{\text{MAX}} \) increases with an increase in the coefficient of friction \( \mu \) of the roll surface and the angle of contact \( \theta \) of the single faced corrugated fiberboard on the guide-roll and, the sheet tension adjustment range of the single faced corrugated fiberboard becomes broader.

4. Flute position control method

4.1 Flute position control theory

Fig. 6(a) shows the method for calculating the sheet tension in order to correct the flute position difference. When the flute position difference is measured \( N \) times and the first average measured value of the flute position difference is \( f(\delta, N) \) and the second average measured value of the flute position

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difference is \( f(\delta_1, N) \), the following equation shows the difference in sheet strain \( \Delta \varepsilon \) between the first and second measured values.

\[
\Delta \varepsilon = \frac{f(\delta_1, N) - f(\delta_2, N)}{L}
\]  

(2)

where,

\( f(\delta, N) \): First average measured value of flute position difference by \( N \) times measurements
\( f(\delta_0, N) \): Second average measured value of flute position difference by \( N \) times measurements

\( L \): Length of interval in measurement of flute position

The following equation shows the sheet strain \( \Delta \varepsilon^* \) corresponding to the second measured value of the flute position difference.

\[
\Delta \varepsilon^* = \frac{f(\delta_0, N)}{\phi_s}
\]  

(3)

From equations (2) and (3), the variation (\( \Delta T \)) of the sheet tension for correcting the third flute position difference \( \delta_3 \) can be obtained by the following equation.

\[
\Delta T = \left[ \frac{f(\delta_1, N) - f(\delta_2, N)}{f(K_p, P)} \right] \phi_s \delta_3
\]  

(4)

where,

\( \phi_s \): Tension relaxation coefficient
\( f(K_p, P) \): Sheet strain by tension 1 kgf/cm corresponding to weight \( P \)/sheet of 1 m²

Thus, when in Fig. 6(a) the sheet tension for correcting the flute position difference shown in equation (4) from the first measured value \( \delta_1 \) and the second measured value \( \delta_2 \) of the flute position difference is varied, the third measured value is to be \( \delta_3 \). However, when there is no variation in the sheet tension, the third measured value is to be \( \delta_3 \).

Fig. 6(b) shows the flow chart of flute position control. After the first flute position difference \( \delta_1 \) is measured, the second flute position difference \( \delta_2 \) is measured and a determination is made as to whether or not the value falls within the allowable range of values.

When the value falls within the allowable range of values, the third flute position difference is measured. When the value is not within the allowable range of values, the sheet tension \( \Delta T \) for correcting the flute position difference shown in Fig. 6(a) is obtained from equation (4). The sheet tension \( T \) is set, and the sheet tension is varied by the brake.

**Fig. 7 Results of flute position control simulation**

It is better to control the flute position by reducing the tension relaxation coefficient \( \phi \) and restraining variation of sheet tension in consideration of sheet tension load on the guide-roll for braking.
The above method is sequentially carried out at every length of interval \( L \) in order to measure flute position thereby making high-precision flute position control possible.

4.2 Flute position control simulation

Simulations were performed to verify the effectiveness of the flute position control theory. Assuming that the pitch of a flute in a low-flute corrugating medium is shorter than that in a high-flute corrugating medium. And assuming that differences in flute position occur, the sheet tension \( T \), variation of the pitch of a flute \( \Delta P \) in the low flute corrugating medium and flute position difference \( \delta \) were simulated in cases where the tension relaxation coefficient \( \phi_\alpha = 1 \) and 0.5 as shown in Fig. 4.

Fig. 7(a) shows the simulation results in the case where \( \phi_\alpha = 1 \). When the new flute position difference is not occurred during the flute position control, variations in the pitch of a low-flute \( \Delta P \) and the flute position difference \( \delta \) can be made to be 0 mm by varying the sheet tension \( T \) two times.

This means that by measuring the first flute position difference \( \delta \), the sheet tension \( T \) for adjusting the second flute position difference \( \delta \) to 0 mm is actuated the first time.

In the case where \( \phi_\alpha = 1 \), the flute position difference can be theoretically adjusted to 0 mm by implementing the flute position control two times. However, it is considered that various difficulties will arise such as rupturing of the sheet on the guide-roll for braking, crushing of flutes and slippage occurring easily because of significant variations in tension during control in the actual operation of the machine.

Fig. 7(b) shows the simulation results in the case where \( \phi_\alpha = 0.5 \) for restraining variation of the sheet tension.

This is the case in which variations in tension is only half of the target tension by \( \phi_\alpha = 0.5 \). It is found that variations in tension per time is reduced and convergence of the flute position difference \( \delta \) is delayed compared with the case where \( \phi_\alpha = 1 \), as can be seen in Fig. 7(a).

Even in this case, the flute position difference \( \delta \) is reduced to within an allowable value of \( \pm 3 \) mm after three times of control frequency. Although control frequency increases to some extent by relaxing variations of the tension as described above, differences in flute position can be corrected by reducing variations in the tension.

From these simulated results, it was confirmed that the flute position control theory was effective.

5. Verification of actual machine performance

Verification of the actual machine consisted of measuring, machine speed under acceleration, deceleration and constant speed conditions, as well as sheet tension and differences in flute position when the type of paper and paper width of the linerboard and corrugating medium are changed and also when the machine speed varied.

Table 1 shows the performance of the double medium corrugated fiberboard production machine obtained from verification of an actual machine. It was confirmed that a maximum flute position difference of the double medium corrugated fiberboard is within \( \pm 3 \) mm at the maximum sheet width of 1800 mm and a maximum machine speed of 180 m/min. for almost all grammages, including a linerboard grammage, of 150—300 g/m² and a corrugating medium grammage of 120—200 g/m² which are in current use can be produced. Further, it was found that the flute position difference is significantly small even in poor pasting of single faced corrugated fiberboard sheets and also at the paper joint point.

6. Conclusion

MHI has recently completed development of a double medium corrugated fiberboard production machine equipped with a flute position control device. The following conclusions can be obtained regarding the performance of this machine.

(1) A high-precision flute position control technique has been developed by obtaining the proper tension taking into strain caused by tension from measurements of the flute position difference for the corrugating mediums having flutes of different heights.

(2) Double medium corrugated fiberboard having a grammage of linerboard from 150 g/m² to 300 g/m² and a maximum flute position difference within \( \pm 3 \) mm can be produced at the maximum machine speed of 180 m/min by using the newly developed double medium corrugated fiberboard production machine.

The first machine was introduced in 1996 and was highly evaluated by the customer. In the future, we will endeavor to realize a machine capable of higher speeds and a reduction in the amount of waste paper.

References