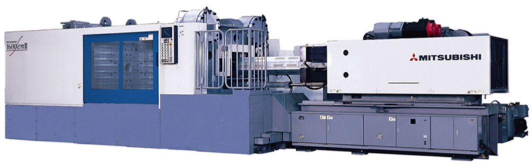
Development of Technologies Contributing to Enhancement of Accuracy and Speed of Injection Molding Machines



HITOSHI OHNUMA*1 SHIKI MATSUO*1
MASAHIRO BESSHO*2 HISANOBU SHINODA*3
TAKASHI MIZUNO*4 NAOKI TODA*5

Injection molding machines are used in various industries, including those manufacturing automotive parts and household electrical appliances, all of which strongly require stable molding quality and high productivity. To meet these needs, MHI has developed unique technologies for high accuracy, high speed injection molding machines including a high rigidity, high speed driving mechanism and a high dispersion, high speed plasticization mechanism through the structure analysis technology, flow analysis technology and control simulation technology possessed by the MHI Technology & Innovation Headquarters. Such unique technologies have contributed to the improvement of performance and reliability of the em II series large electric injection molding machines.

1. Introduction

In manufacturing plastics products and parts, electric injection molding machines have been increasing market share while also increasing in size because of their cleaner and more energy efficient operation compared with conventional hydraulic injection molding machines.

The use of electric motors for injection molding machines that started in Japan has been followed by manufactures not only in Europe and the United States, but also in China. They have already put small electric injection molding machines on the market. The use of electric motors for large injection molding machines has more challenges than that of small injection molding machines, the loss of reliability caused by deformation resulted from clamping force and inertia force generated when the heavy mold or movable platen accelerates or decelerates and the deterioration of chromatic dispersion with the high speed screw. In 2006, using structure analysis technology, control simulation technology and resin flow analysis technology, MHI developed and placed on the market the 3000em, the world’s first large electric injection molding machine with a mold clamping force of 3000 tonf.

Since then, to meet customer needs for further accuracy and speed, MHI has implemented the development of technologies such as structure analysis of clamping mechanisms including ball screws and molds, evaluation technology of service life of ball screws, servomotor multishaft synchronous control technology, resin dispersion analysis of screws and visualization technology of resin flow. This has resulted in a model change to the em II series large electric injection molding machines employing a lighter center press platen that can suppress flashing in molding, higher speed mold opening/closing and high chromatic dispersion, as well as a high speed plasticization screw that rotates at high speed, attains better chromatic dispersion and enables quick color change.

*1 Resarch Manager, Nagoya Research & Development Center, Technology & Innovation Headquarters
*2 General Manager, Materials & Structure Laboratory, Nagoya Research & Development Center, Technology & Innovation Headquarters
*3 General Manager, Power Electronics & Systems Laboratory, Nagoya Research & Development Center, Technology & Innovation Headquarters
*4 General Manager, Engineering Department, Mitsubishi Heavy Industries Plastic Technology Co., Ltd.
*5 Deputy General Manager, Engineering Department, Mitsubishi Heavy Industries Plastic Technology Co., Ltd.

2. Features of em II series large electric injection molding machines

Figure 1 shows an outline of the technological development of the em II series large electric injection molding machines.

The main feature of the em II series is the employment of MHI's unique, space saving 2-platen type mold clamping mechanism. The machine employs an electric hybrid system that combines the mold opening/closing system driven by a 2-shaft synchronous servo motor, the electric servo split nut mechanism and a clamping mechanism driven by an energy efficient, low noise eco-servo pump system. Thus, given the benefit of the high speed, high accuracy repeatability of the electric system and the benefit of a four-point even hydraulic clamping system which is excellent in controlling clamping forces, the machine is space saving (the machine length is less than 15 meters, about 25% shorter than competing machines with a toggle link type mold clamping mechanism) and is energy efficient (reducing energy consumption by 60% compared with hydraulic injection molding machines), making the em II series the world's shortest electric injection molding machine.

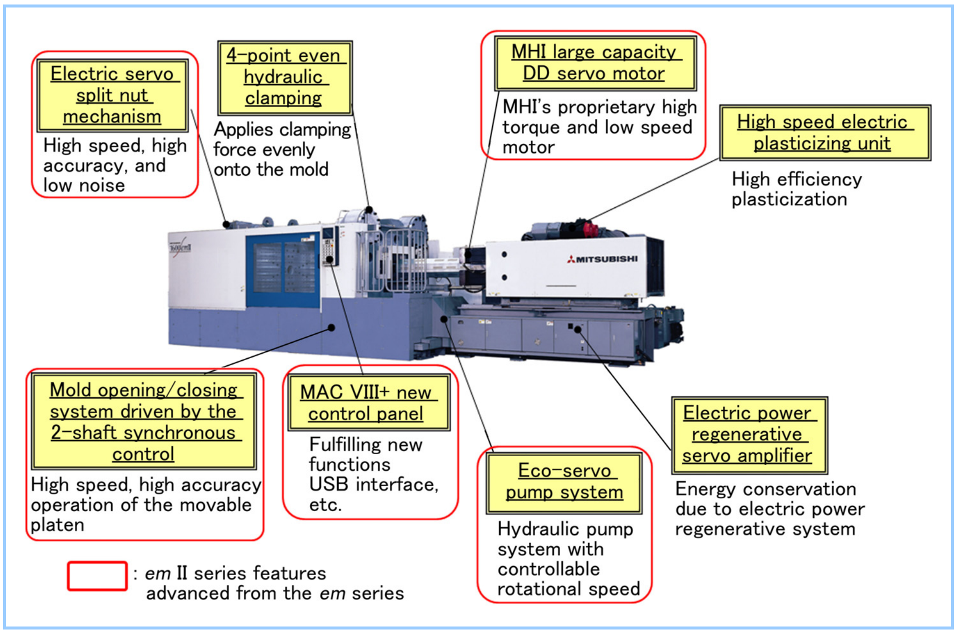


Figure 1 Outline of technological development

Synchronous control of MHI's large capacity, quick-response DD (direct drive) servomotor for high speed injection mounted on the injection shaft drive mechanism and the electric high speed plasticizing unit enable high productivity. In addition, the MF-UB high chromatic dispersion, high speed plasticization screw is available for the suppression of the color heterogeneity of coloring pigment.

3. Development of coupled structure analysis and technology for evaluation of ball screw service life

3.1 Coupled structure analysis and center press platen

Platen design is regulated by deformation rather than stress because a gap between mold elements appears at the parting face and flashing occurs on molded products when the platen deforms significantly. In the past, a platen's form was determined through analysis of strength and rigidity for the platen alone, with boundary conditions including load on the contact face of the smallest mold and the clamping force application point.

Since the 2-platen type mold clamping mechanism applies the clamping force evenly to the four tie bars, the effects of the mold temperature and molds with an eccentric cavity profile are less profound compared with the toggle type mold clamping mechanism. This enables the clamping accuracy to be maintained for a long period of time, among other benefits. However, as with the toggle type mold clamping mechanism, the 4-point mold clamping mechanism has the shortcoming that the bending deformation of the platen supported at both ends is likely to adversely affect the mold. This causes a gap formation between mold elements, making flashing more likely, particularly when a large mold such as a bumper mold is used.

MHI developed and conducted a mold gap formation analysis consisting of a structure analysis that combined the platen and the mold structure and a flow analysis of resin inside the mold. Based on the analysis results, MHI has developed a unique center press platen that employs a rib structure to allow the lines of force to flow from the tie bar loading points through the center of both movable and stationary platens so that the forces apply evenly.

Figure 2 compares the mold clamping mechanisms.

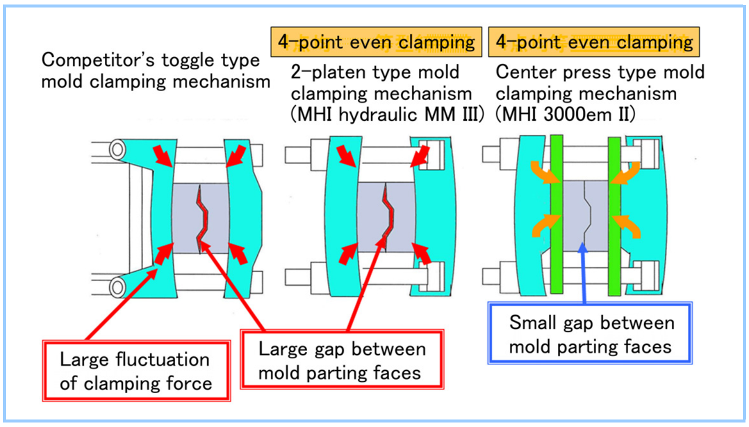


Figure 2 Comparison of mold clamping mechanisms

3.2 Development of mold gap formation analysis method

A model with the mold located between the platens (stationary and movable) was created as shown in **Figure 3** to establish a method of analyzing the gap formation between mold parting faces by using contact analysis. First, the resin pressure distribution in the mold obtained by resin flow analysis was analyzed even further as boundary parameters for the structural analysis to obtain the contact load distribution over the mold parting faces. As shown in **Figure 4**, the parting faces are not in contact with each other over a relatively wide area. In particular, the area around the gate where the molten resin pressure is relatively high is predicted to be in the condition of mold gap formation. Actual injection forming tests took place using the mold of an automobile part where the gap formation between mold elements was measured at the gap sensor positions and compared with the results of analysis. The analyzed values are in the range of -30% to +10% of the actual measurements, confirming that the newly developed method is practical for quantitatively analyzing the gap formation between mold elements.

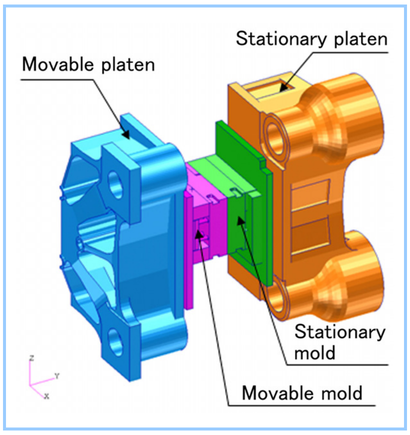


Figure 3 Model for analyzing gap formation between mold elements

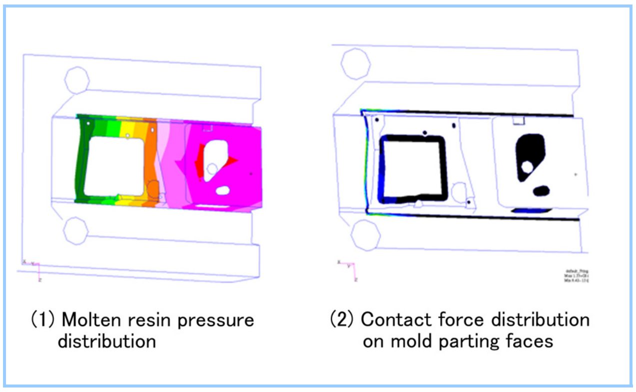


Figure 4 Internal mold analysis

3.3 Flashing-less operation by center press platens

The method of mold gap formation analysis was used to obtain the gap formation between mold elements for a sample mold that simulated a bumper profile. As shown in **Figure 5**, the new center press platen reduces the gap to nearly zero at central part E of the mold. With this outstanding improvement in the gap around the gate, the new center press platen is expected to significantly reduce flashing.

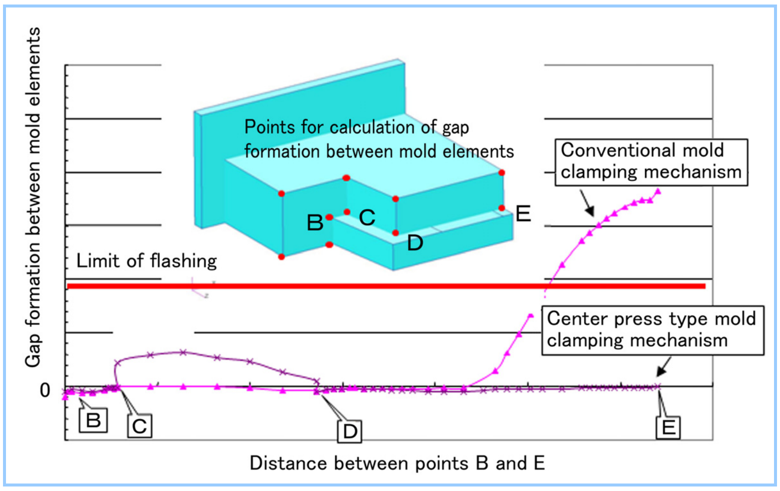


Figure 5 Comparison of gap formation between mold elements between center press platen and conventional platen

3.4 Development of ball screw contact pressure distribution analysis method

The movable platen is opened/closed by the 2-shaft ball screw that is installed on both sides and driven by the servomotor. The ball screw bears not only axial load for driving the movable platen and the mold, but also increased contact pressure due to bending of the ball screw because of deformation of the platen and the ball screw supporting structure or their mounting surface inclination. This may shorten the ball screw service life.

As a measure against this, MHI developed an analysis method consisting of not only an analysis of the stress and deformation of the supporting structure components of the platen and the ball screw, but also the contact pressure distribution of the ball screw generated by such deformation. **Figure 6** shows the analysis model of the mold opening/closing mechanism, the stress analysis of the platen, the deformation analysis for acceleration/deceleration and the ball screw contact pressure distribution analysis for acceleration/deceleration.

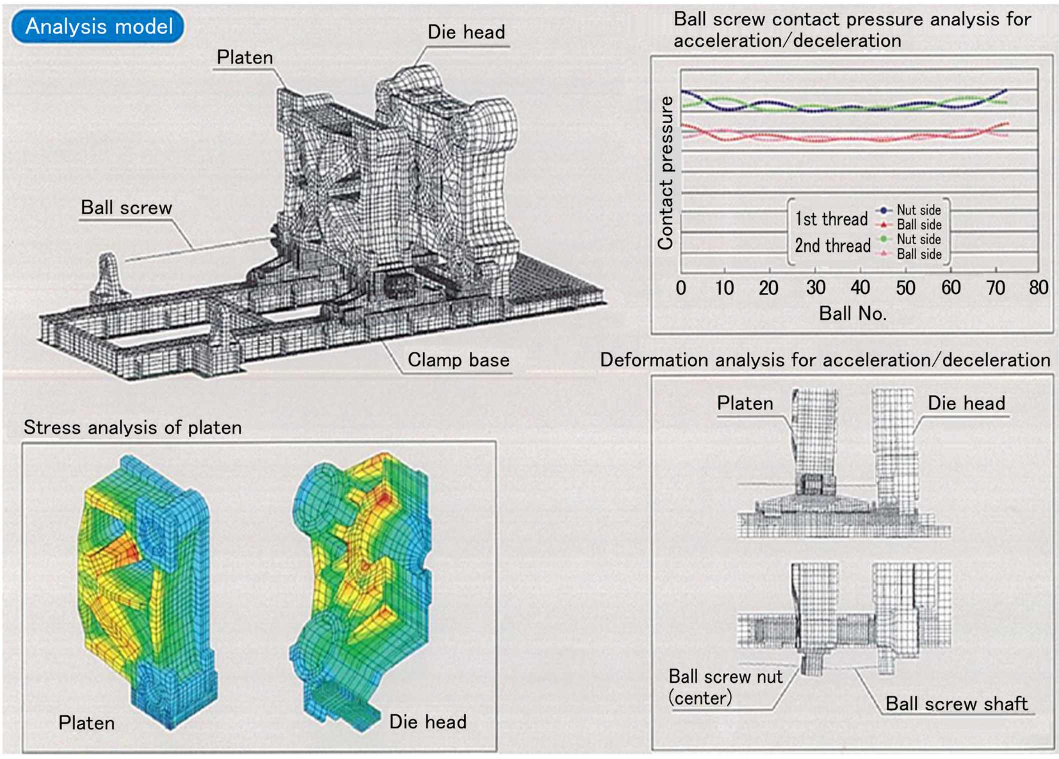
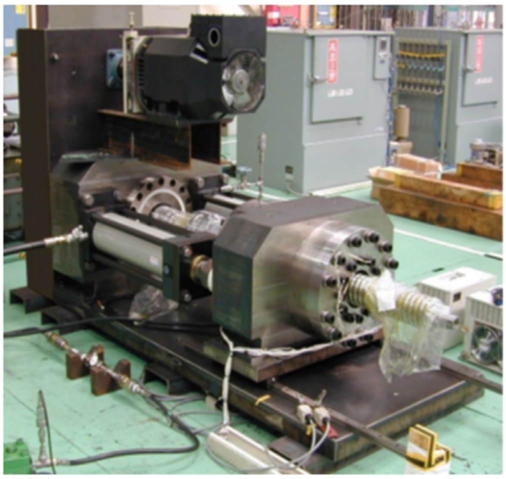


Figure 6 Analysis consisting of mold opening/closing mechanism and ball screw contact pressure

3.5 Development of ball screw service life evaluation technology

An evaluation method of ball screw service life under rolling fatigue had not been established, even by ball screw manufacturers. MHI developed a unique ball screw service life evaluation technology.

MHI made a ball screw durability element testing machine that reciprocates an actual sized ball screw while applying load with the use of a hydraulic cylinder to implement verification tests. **Figure 7** shows the ball screw durability element testing machine. First, stress and deformation of the nut and the load were measured, and then a durability test with load acceleration was performed.



- Durability test (ball screw service life evaluation)
- Load test at maximum injection speed, maximum pressure and maximum stroke load

Figure 7 Ball screw durability element testing machine

The durability test was performed until flaking due to rolling fatigue occurs for 5-level contact pressure. A Weibull plot of breakdown probability for each contact pressure was used to calculate the L10 life, and then the rolling fatigue life formula was arranged. The occurrence of flaking was evaluated by observing the surface conditions of the rolling threads and the ball. **Figure 8** shows the relationship between the maximum contact pressure of the ball screw and the life curve.

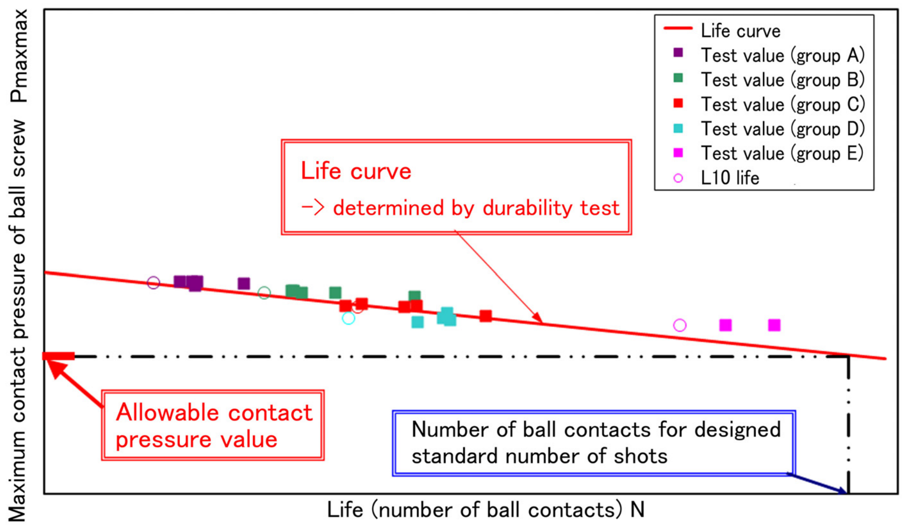


Figure 8 Ball screw life curve

This developed technology made it possible to find the allowable contact pressure that attains the designed standard number of shots under the actual maximum load. Then the optimum form of the mold clamping mechanism could be obtained by repeating the coupled analysis so that the maximum contact pressure of the ball screw decreases to the allowable value.

4. Multishaft synchronous direct drive injection unit

To enable the high speed, high response injection required for molding thin walls, the em II series employs multishaft synchronous control that synchronously drives the four direct drive (DD) servomotors directly connected to the four shafts of the ball screws without using mechanical means such as synchronous drive belts. This reduces the inertia in the injection mechanism and improves the speed response that is essential for thin-wall molding and at the same time eliminates the factors that would otherwise deteriorate control accuracy stability due to the elongation or dislocation of the belts. As a result, power transmission loss, noise and dust are also reduced.

Figure 9 compares drive systems. Competing machines use a speed reduction mechanism linked by timing belts and large-diameter pulleys, which has a large inertia and results in response improvement limits.

Therefore, mobilizing MHI's unique motor electromagnetic analysis engineering and control simulation evaluation technology, MHI has developed large capacity DD servomotors with low rotational speed and high torque characteristics and a beltless multishaft synchronous control system dedicated to the injection molding units. This system has the benefit of not only improving response, but also long-term stabilization of injection accuracy due to the elimination of the need for belt tension adjustment or belt changes. **Figure 10** shows the system configuration.

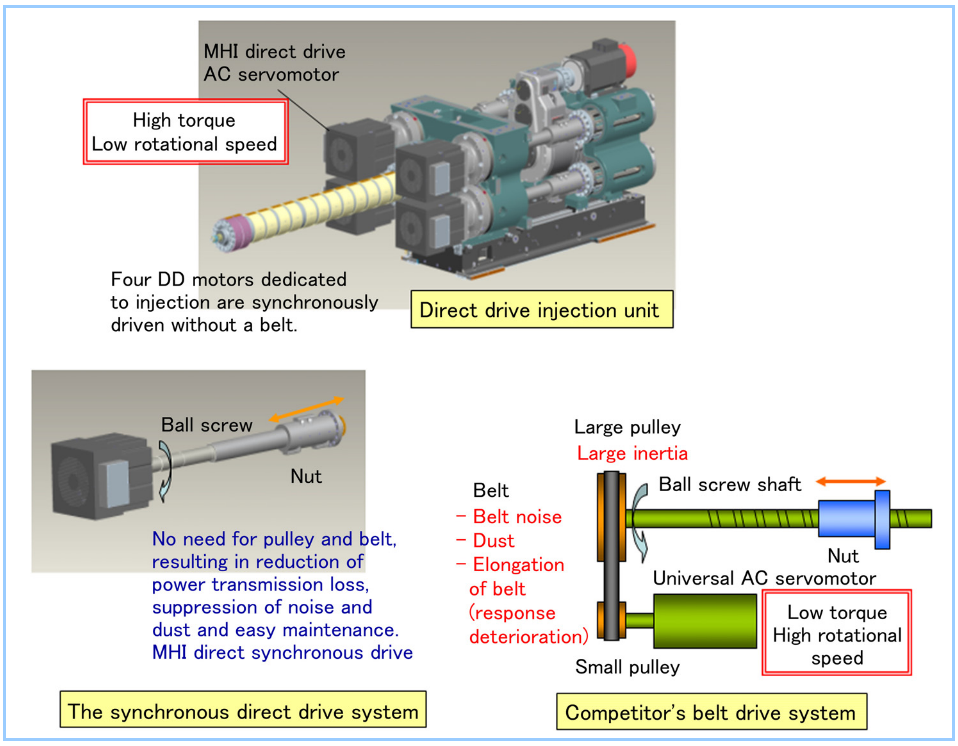


Figure 9 Comparison of injection units

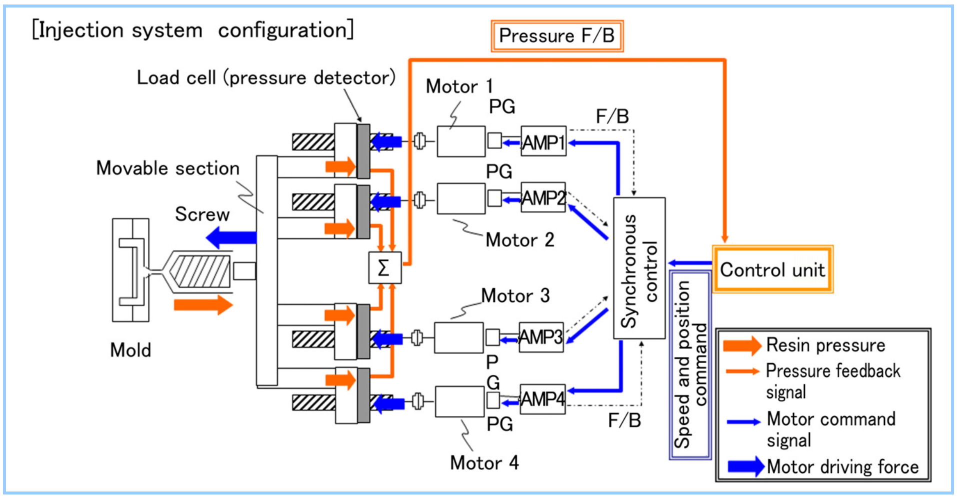


Figure 10 4-shaft synchronous control system

5. High dispersion, high plasticization and quick color change

MHI's double-flight type UB screw has a long barrier for the separation of liquids and solids and segregates unmolten resin from molten resin to ensure a homogeneous plasticizing quality, even at a high speed rotation. For material cost reduction, there has been growing use of recycled materials and pigment. However, such materials are likely to cause chromatic dispersion failure of molded products when screw rotational speed is increased for the reduction of molding cycle time.

To enable high dispersion, even in high speed plasticization, MHI developed the MF-UB screw, which is a UB screw equipped with a high dispersion multi-fin type mixing system on the tip. **Figure 11** illustrates the MF-UB screw, analyzes the mixing dispersion, visualizes the dispersion process and depicts the improvement of chromatic stagnation.

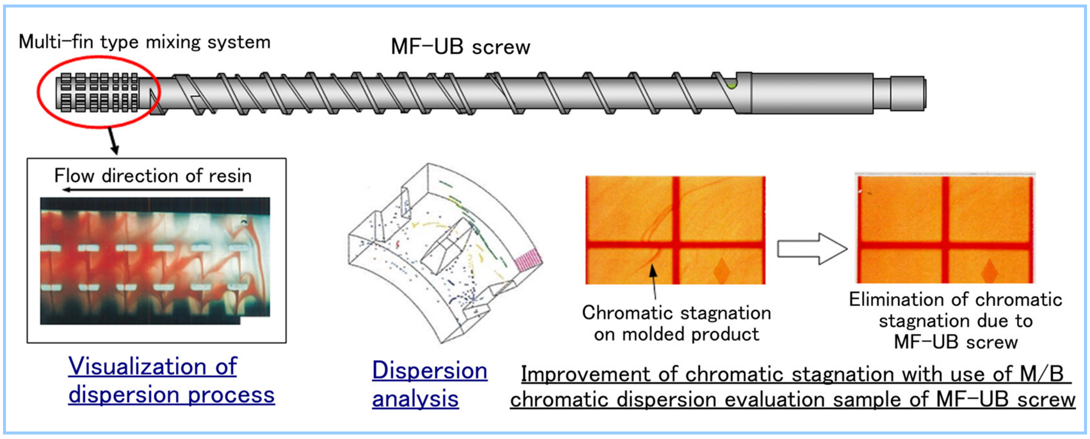


Figure 11 High dispersion and high speed plasticization attained by MF-UB screw

The form and layout of the fins on the multi-fin type mixing system have been optimized by visualization of the dispersion process through the use of simulated molten resin liquid and by molten resin flow analysis to obtain a form with a more efficient agitating effect. Thus efficient agitation for actual molten resin is provided.

As a result, plasticization for molding bumpers that causes no chromatic dispersion failure and enables a molding cycle time of 25 seconds at a mixing ratio of pigment master batch to resin of 1% is attained.

Such enhanced dispersion also eliminates chromatic stagnation at color changing, therefore reducing the number of shots for color changing by half.

6. Conclusions

To meet demands for improved quality and reduced injection cycle time for injection molding products, MHI has developed unique high accuracy, high speed technologies and has put an energy efficient and space saving injection molding machine on the market. The machine offers high productivity with reduced running costs to not only the manufacturers of large injection molding products for automobiles, but also to plastic injection molding machine users such as those producing large household electrical appliances. To continue to answer customer needs, MHI is willing to utilize its comprehensive technical capabilities to not only improve machine performance, but also to develop new machines to improve the quality of injection molding products.