Development of the World's Fastest Servo Press Line For Manufacturing Automotive Body Panels

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1. Introduction

HONDA, in cooperation with AIDA Engineering, Ltd., has developed a revolutionary servo press line that enables the deep draw-forming of automotive body panels at the world's highest productivity levels (max. of 18 strokes per minute (SPM)) that was not possible using conventional press lines, and has installed it in the HONDA Motor Company's Suzuka Plant (Photograph 1). In order to satisfy the contradictory requirements of deep draw-forming and high productivity, the conventional die design concept of modifying the dies to match the production line through trial and error was discarded and a revolutionary press production system was developed. This press production system optimizes the press forming requirements and the panel conveyance motions for each part being produced in order to achieve high-precision integration with the dies, which has thereby enabled the high-efficiency production of deep-drawn body panels and unparalleled short startup leadtimes for new models, and it has also enabled energy-efficient production. HONDA is planning a strategic expansion of this production system and press line to its production plants around the world as the HONDA global standard.

2. Background and Goals

In the midst of the changing global economic conditions in recent years, the automotive industry has found itself in an environment where together with very high expectations (in terms of enhanced product competitiveness in response to the demand for even

(Photograph 1)

lower costs, even more design advances, higher quality, and improved environmental performance) the production systems themselves have also been enhanced because of the shift from large lot production to diversified lot production and the demand for lower energy usage and material usage during production, and production has thus diversified to the point where it has even been evolving in response to environmental issues. In terms of its production of automotive body parts using presses, HONDA was using conventional transfer and tandem press lines composed of mechanical presses and this resulted in major technological constraints in the production of such parts. Moreover, after considering future difficulties with accommodating major technological advances and future customer requirements and also its desire to reduce the high energy consumption required for production, HONDA decided that it was necessary to revolutionize its press line production systems using next-generation technologies.

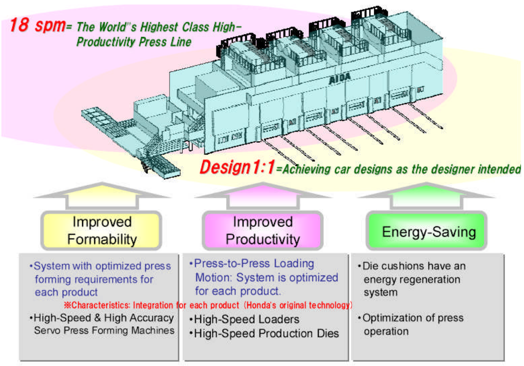
Accordingly, the development of a next-generation press production system was initiated in 2005 with the aim of achieving an overwhelming competitive advantage that could serve as a global benchmark for the next 30 years and enable both the ultimate pursuit of production efficiency and the accommodation of evolutionary changes in its products. Specific target metrics are shown in Table 1.

Item	Development Target
Formability Improvement	Conventional +50mm Deep drawing design
Cost Redustion	vs.Conventional -10% or more
Productivity Improvement	Fastest in the world 18spm
Energy Saving	vs.Conventional -30% or more

(Table 1)

3. Development Engineering Overview

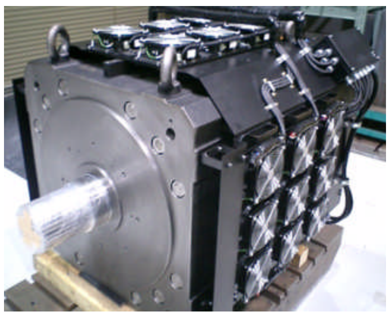
The press line that resulted from this development is a tandem press line composed of 4 servo presses and servo feeders (conveyance equipment that moves panels from one process to the next). Though one of the goals of using servo technology in its equipment was to improve cycle times via the synchronized control of the presses and associated conveyance equipment and allowing the differentially-phased operation of the presses, the primary goal was to optimize the press forming conditions and the panel conveyance conditions for each product. On conventional press lines, the slide motion of each press in the line is almost uniform, and each parameter is optimized in order to attain the maximum formability characteristics of the press, the maximum flexibility of the conveyance equipment, and the maximum conveyance speed. This new press line has allowed the achievement of both deep draw-forming that was not possible using conventional methods and the world's highest level of productivity. The following provides an overview of the development technologies used to make this new system a reality. (Figure 1)



(Figure 1)

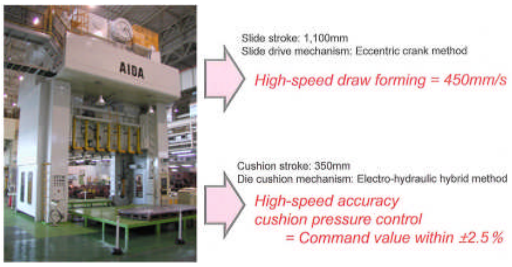
3-1. High-Speed, High-Accuracy Servo Presses

The primary goals during the development stage of the servo press forming machines were the ability to perform deep draw-forming and to achieve high press stroking speeds (27 SPM when running in Continuous mode). First, a slide stroke length of 1100 mm was selected to accommodate the deep draw-forming target values. An eccentric crank motion system was adopted for the slide drive mechanism because of the importance of high slide speed during the forming portion of the press stroke, especially in the vicinity of bottom dead center. The slide of this long-stroke press is driven at high speed, and rapid acceleration and deceleration is also achieved via the servo controls. Compared with a link mechanism, the eccentric crank mechanism design is simpler, which also simplifies the motion controls. On the other hand, a great deal of torque is required to drive such a press and to attain the requisite forming tonnage, and thus it was necessary to develop a low-speed, high-torque servo motor for these large-capacity servo presses. The servo motors for this development project (Photograph 2) were manufactured by the press machinery manufacturer AIDA Engineering, Ltd., using its independently developed technologies. Based on the specification requirements provided by HONDA, AIDA optimized the structural designs, the magnetic circuit designs, the cooling architecture, and the CNC controls of its servo motors.



(Photograph 2)

This resulted in the achievement of unique large-capacity servo presses (Photograph 3) that operate at high speeds with high accuracy. Additionally, the highest capacity draw-forming press (23000 kN rated capacity) in the line is powered by 4 servo motors, and it also contributes to a smaller installation footprint and lower equipment investment costs.

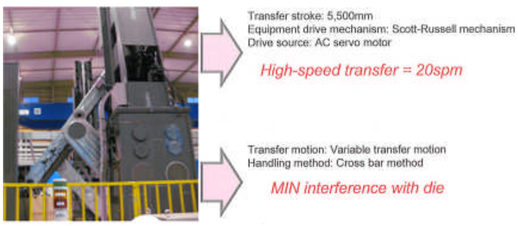


(Photograph 3)

At the same time, in order to achieve the targeted deep draw-forming requirements, high-precision variable controls were also necessary for the die cushion pressure to enable it to track with the press motion. The die cushion equipment used in the draw-forming press in this new line utilizes a hybrid motorized hydraulic system equipped with NC controls. Small high-speed servo motors are used to control the pressure inside hydraulic cylinders to enable high responsiveness to die cushion pressure fluctuations during the forming portion of the press stroke and high-precision pressure controls that are within ± 2.5% of the commanded pressure value. Additionally, the electrical power regeneration feature in the die cushion enables 70% of the working force to be recaptured, which also helps to lower energy consumption.

3-2. High-Speed Press-to-Press Conveyance Equipment

During the development of the high-speed conveyance equipment (Photograph 4), the goal was to achieve a conveyance system that would directly convey the workpieces from one press to the next.



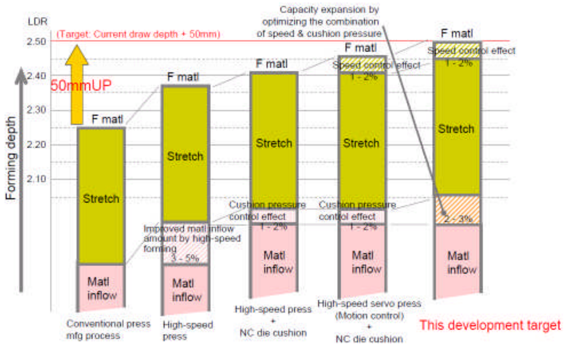
(Photograph 4),

In order to achieve the targeted line SPM, the ability to complete a 5~6 meter conveyance stroke within 1.5 seconds was required. However, it would be difficult to achieve this requirement using a simple sliding-type mechanism, and as a consequence, it was necessary to combine a long arm to a swiveling pivot shaft. The drive method for the arm is based on well-known Scott Russell linear linkage, and it has a newly developed link mechanism that enables motion in the lift direction by replacing the connection point between the feed arm and the drive arm with a short linkage. In the case of a conventional Scott Russell linkage, it is customary to raise the entire unit in order to achieve motion in the lift direction, which means that as the conveyance distance lengthens the unit as a whole becomes larger and larger. However, this newly developed mechanism does not require the lifting of the entire unit--the additional short linkage only needs to be actuated--and this is extremely advantageous for the high-speed motion required for tandem lines. Additionally, because the linkage in the linear direction is achieved by controlling 2 axes on one side plus 1 tilt axis, even when multiple conveyance equipment units are connected the total number of controlled axes can be kept to a minimum.

This press-to-press conveyance equipment was the result of a joint development project with AIDA Engineering, Ltd. A comprehensive control system is crucial to achieving high-speed synchronous control of the entire press line, and a priority has been placed on selecting systems based on their synchronization control performance with respect to the servo press machines. In order to derive the maximum benefit from the high-speed, high-accuracy control of the position of the servo press slide throughout its entire motion range from top dead center to bottom dead center, this synchronized control system not only provides synchronized controllability of the conveyance equipment it also constantly monitors its positional relationship with the press slide. It is also equipped with interference prevention features to deal with a wide variety of possible risks. Moreover, the conveyance equipment drive mechanism incorporates know-how obtained during the development of the servo presses, and just like a servo press it uses a low-speed, high-torque servo motor in combination with a gear drive system to achieve the power performance required for high-speed operations. Especially in the case of the above-mentioned link drive mechanism, the drive power is transmitted internally via the swivel arm, which enables motors and other heavy items to be mounted in a stationary position, which enables the feed arms and drive arms to swivel at high speed. The body panel conveyance system incorporates the high-speed conveyance configurations used on transfer press lines, i.e., a crossbar cup feed system. The end of the feed arm is equipped with a tilt feature that swivels in the vicinity of the crossbar center axis, and a tool section mounted on the crossbar is used to handle the other swiveling and/or shifting motions required in the vicinity of the axis.

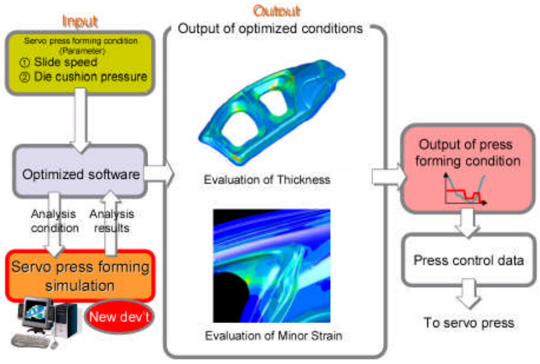
3-3. Optimized System for Forming Conditions

Optimized press forming conditions are required in order to maximally leverage the capabilities of a servo press and to achieve the goal of deep draw-forming. Formability is improved by optimizing the press speed during the forming portion of the stroke by controlling the speed of the press slide and by optimizing the material flow characteristics by controlling the die cushion pressure （Figure 2） shows the target deep draw-forming values and the degree to which each parameter contributes to the final result.



（Figure 2）

However, based on prior tests, we knew that the forming conditions required to achieve deep draw-forming that was 50 mm deeper than conventional techniques were only found in an extremely narrow range, and additionally, we knew that the forming conditions varied depending on the shape of the part being formed. The most rudimentary method for finding optimal forming condition solutions is to actually manufacture dies and then perform forming trials under various conditions, but this involves a tremendous amount of time and expense. Moreover, when forming automotive body parts--and especially when deciding upon the design of exterior body panels--it is necessary to ascertain whether forming is possible or not at a very early stage in the development process, and it was a real problem because it is not possible at that early stage to determine whether such forming would be possible through a trial and error process that uses dies. In this development project, press forming simulations were used instead of trial and error testing in order to develop a system that would deliver optimal forming conditions. An overview of this system is shown in （Figure 3）.

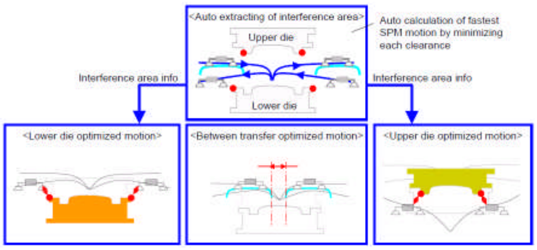


（Figure 3）

Press forming simulations are analyzed and the results are evaluated by dividing the press forming process into a number of discrete stages and then using optimization software to fine-tune the press forming speed parameters and the die cushion pressure parameters at each stage. Based on the final analysis results of the minimum primary strain and the results of the material thickness reduction rate, the optimal forming conditions are determined by selecting a central value within a range that has a good balance between both factors, and then the servo press motion controls and the die cushion pressure controls are converted into data. However, in existing press forming simulation software, the analysis function assumes that the relationship between the material stress and strain and the frictional coefficients are always uniform, and thus there were problems because even when the forming speeds were changed in the simulation software the resulting analysis results remained the same. As such, we also developed the servo press forming simulation software used for this system. When simulating the speed-dependent relationship between material stress and strain, the relative speed of the adjacent contact points of the forming model during the forming process was calculated, and that was used as the strain speed, and a module was added that varies the relationship between stress and strain depending on this calculated strain speed. And a method was also incorporated for the frictional coefficient that correctly simulated the effects of relative speed and contact surface pressure. This resulted in a press forming simulation that would correctly output the forming results based on variations made to each of the forming parameters. This system enables us to determine during an early stage of new automobile development whether a design that approaches the maximum capabilities of a servo press can be used or not, and it allows the press forming conditions for each part to be automatically set during the production preparation stage.

3-4. Optimized System for Conveyance Motion

When producing deep-drawn parts at high speed, the goal is to increase the flexibility of the product conveyance equipment motion between each process while at the same time reducing wasted motion to the greatest extent possible. In conventional press lines, the number of conveyance motions is limited to a few patterns, and because it is necessary to design dies that will match these motions it constrains the product shape and in some cases productivity (SPM) may have to be sacrificed. In this project we turned the conventional concept on its head, thereby enabling the conveyance of products using optimal motion based on the shape of the dies, and we developed a system that will automatically generate that motion. The concept behind conveyance motion optimization is shown below. (Figure 4)



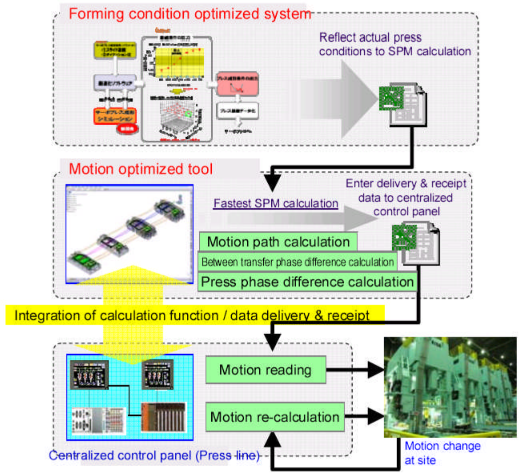
(Figure 4)

① Conveyance distances are shortened by making the clearance between the lower die and the conveyance tools as small as possible.

② The time the equipment spends inside the press is shortened by keeping the allowable distance between adjacent conveyance tools as short as possible.

③ The non-forming time of the press is shortened by keeping the clearances between the upper die and the conveyance tools as small as possible.

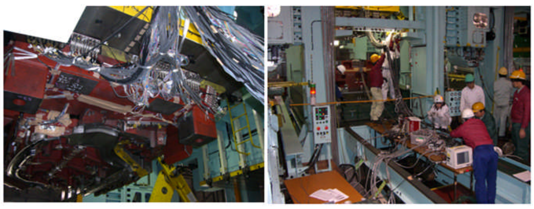
Based on the above concept, 3-D die design data is used together with the press motion data (created using the above-mentioned press forming condition optimization system) to automatically calculate the conveyance motion for each process stage. The calculated conveyance motion is transmitted together with the press forming conditions to the recipe databank in the servo press line's centralized control panel as the press operation data. (Figure 5) These systems enable the line operator to simply call up the operation data for each product from the recipe databank, thereby allowing the optimal forming conditions for the high-speed production of deep-drawn parts.



(Figure 5)

3-5. Die Designs Suited for High-Speed Production

When developing this high-speed line, the speed of the press itself during a forming cycle reached a maximum of 27 SPM, and the slide stroke length was increased to 1100 mm, which thereby increased the maximum speed during the forming portion of the stroke by a factor of approximately 1.7 times, and it was thus deemed necessary to change the design of the dies and the materials of the components used in the dies. We then measured the die behavior and stress conditions when actually running at high speeds, and determined which components would require countermeasures (see Photograph 5).



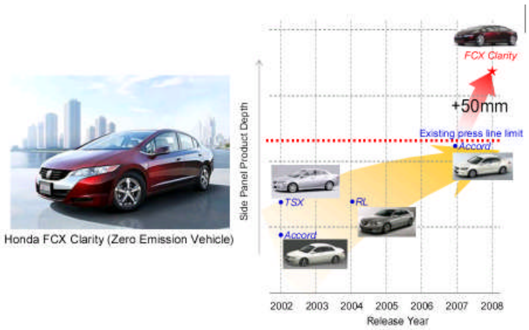
(Photograph 5)

Of those components requiring countermeasures, if there were areas where standardized products could be used, the design standards were changed to match these products, but a problem cropped up due to the high impact load being exerted on the suspension pins used for the suspension of structural components in the upper die (bend pads, etc.) because the standardized parts used up to that time would only last a few thousand shots before breaking. As a result, in this project HONDA developed an original design for these pins that incorporates cushioning media that internally disperse and absorb the impact loads. We have verified that the durability of these pins under actual high-speed production conditions exceeds 300,000 shots, and we believe that they contribute to stable production.

4. Development Results

4-1. Deep Draw-Forming

Practical examples of deep draw-forming in this development project are shown in （Figure 6）.



(Figure 6)

The FCX Clarity is a fuel-cell hybrid automobile introduced to the market by HONDA in 2008. In order to achieve the 3-dimensional shapes of the tapered rear section of the cabin and the projecting rear fender, deep draw-forming technologies that exceeded conventional press line forming limitations by 50 mm were required for the exterior side panels. In this development project, 2 approaches for the deep draw forming of the exterior panels were compared. One approach was to actually manufacture the dies and then perform repeated forming trials. The other approach was to use the above-mentioned system that optimizes the press forming conditions. We used dies to perform repeated trial-and-error forming tests that spanned approximately 6 months, but in the end we were unable to achieve formed parts that were free of cracks. However, using the forming condition optimization system we were able to derive the optimal forming conditions after spending approximately 60 hours making calculations, and using these derived forming conditions we were able to achieve good parts that were free of cracks and wrinkles in the very first trial. This comparative testing process provided clear validation of the tremendous benefits of this production system.

4-2. Improved Formability and Productivity

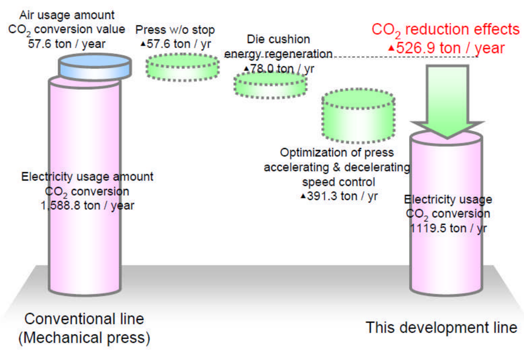
Table 2 shows the forming depths and productivity levels (SPM) of representative parts formed on this servo press line. In terms of forming depths, this line enables deep draws that are 50 mm deeper than previous methods used for forming the deep draw-forming designs used for exterior side panels and front fenders. In terms of production, we have verified that productivity has been improved by 40~50% for all produced parts compared to transfer press applications. Additionally, for parts such as door skins that are comparatively flat and have only shallow drawing depths, we have achieved the world-record production speed of 18 SPM.

Name of Parts	Drawing Depth	Stroke Rate Of Conventional Line	Stroke Rate Of Servo Press Line	Plus %
Side Panel Outer (Deep Drawing)	250mm	-	14.5spm	-
Side Panel Outer (Conventional)	200mm	11.0spm	16.0spm	+45.0%
Front Fender Panel (Deep Drawing)	270mm	-	13.0spm	-
Front Fender Panel (Conventional)	220mm	11.0spm	15.3spm	+39.1%
Door Outer	60mm	13.0spm	18.0spm	+38.5%
Door Inner	140mm	12.0spm	16.9spm	+40.8%

(Table 2)

4-3. Energy-Saving Production

Figure 7 shows the reduced production-related energy consumption achieved by this newly developed press line. Air consumption on servo-driven press equipment is lower compared to a conventional mechanical press where air is used to operate the clutch and brake unit that stops the press at top dead center. Additionally, electrical power consumption has also been greatly reduced due to the power-saving benefits of the above-mentioned die cushion energy regeneration system and the application of operation motion that constrains the joule heat generation when the servo presses are running in Continuous mode. Compared to a conventional mechanical press line, this servo press line achieves over a 30% reduction in energy consumption during production (this is equivalent to 500 tons of CO_2 on an annual basis).



Achieved 32% reduction of press production energy

(Figure 7)

5. Summary

This development project has enabled HONDA to achieve a production system that makes possible the high-efficiency forming of deep-drawn parts on the fastest servo press line in the world. While continuing to make even further enhancements to this servo press line, HONDA is planning to deploy such lines to its manufacturing plants around the world. These servo press lines will serve as the benchmark for high-speed lines used to produce automotive body parts, and they are expected to serve as the driving force to a revolution in the future press production of automotive body parts.

By leveraging this press production system to the greatest extent possible, HONDA will continue to bring to market “appealing products that exceed customer expectations” in a timely manner.