

Development of Stamped Frames Made of High-tensile Steel Plates with Light Weight and High Production Efficiency for Small Motorcycles

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ABSTRACT

A lightweight stamped frame with high production efficiency was developed for application in small motorcycles produced in large numbers. This development was motivated by the challenge to produce the lightest frame in this category of 150 cm³ displacement motorcycles, and weight reduction was pursued by the application of thin plate material for its production. To ensure the necessary strength and stiffness, high-tensile steel plates were used and the suitable cross-sectional profiles of the frames were newly devised. In the production using high-tensile steel plates, there exist rigorous restrictions in the orientation of parts partitioning, because they are highly resistible against the extension force and the press-forming of the parts with a large depth is considerably difficult. To cope with those restrictions, the forming parts were designed to have limited depths by employing the structure having flanges for welding at the upper and the lower portions of the parts enabling the coupling-type assembly along their horizontal direction while achieving enhancement of the strength, along their cross-sections, in the direction of the main load application. Moreover, the manufacturing time was shortened by normalized manufacturing processes and the simplified parts correction process brought by the application of the separated structure of the frame, which formerly was a mono-bone structure. However, when the stamped frame was constructed with the front-rear separation structure, the yield rate of the parts per plate went down and became an issue because of the complexity of the parts shapes. To cope with this issue, multiple parts blanking, in which multiple parts are cut out at one time, was introduced by adjusting the thicknesses of the yielding plate parts into a few standardized thicknesses. Consequently, the weight reduction was achieved while minimizing the increase in the manufacturing processes and the decrease of the yield rate, even though the frame parts were downsized and divided into a larger number of parts. Through these measures, a 30% reduction in weight and 30% reduction in process time were realized compared to the current stamped frame manufacturing processes, while maintaining the equivalent strength and stiffness of the frame.

1. Introduction

In response to environmental issues such as global warming and air pollution, efforts to reduce CO₂ emissions have become an urgent issue in the area of motorcycles. In particular, the market for small motorcycles is expanding annually in developing countries, and with an increase in the number of units being produced, the reduction of CO₂ emissions at the manufacturing stage is becoming an issue in addition to reductions when the vehicles are running. This makes it necessary to introduce diverse measures to improve fuel economy and rationalize production processes. In the area of frame components, the realization of weight savings is a standard method of improving fuel efficiency. It is particularly essential to realize weight

savings in the frame, which represents a high proportion of the complete vehicle. Further, in addition to responding to environmental issues, efforts to reduce the weight of parts and increase the efficiency of manufacturing are necessary from the perspective of the manufacture of cost-competitive products.

Honda is responding to the annually expanding market for small motorcycles in Brazil. As part of these efforts, it was necessary to increase efficiency in the production of the CG series, which is produced in the highest numbers (more than 800,000 units per year as of 2011). The CG series is subjected to severe use conditions, for example being ridden on rough road surfaces and while heavily loaded. It is therefore essential to produce frames possessing sufficient strength and stiffness to resist these conditions. In order to

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satisfy these demands, stamped frames have been used for the series since 1999. These stamped frames were created with a focus on production efficiency, but with the increase in the number of units manufactured, it was necessary to further increase production efficiency.

Honda has realized weight savings in the body frames of various small motorcycles, and its pipe frames have been optimized for their specific use environments⁽¹⁾. In the case of stamped frames, while efforts have previously been made to realize weight savings, due to factors including restrictions on the yield from the materials, significant outcomes were not obtained. The production of stamped frames is highly dependent on production equipment, and it was therefore also essential to make changes to the production process in order to realize weight savings.

A new, lightweight stamped frame with high production efficiency and able to contribute to the resolution of global environmental issues has been developed with consideration of the use conditions and production demands described above, and it was applied to the CG150 of the 2014 model year that began production in July 2013 (Fig. 1). This paper will discuss the technological specifics of the new frame.



Fig. 1 CG150 2014 model year

2. Development Goals

The following three development targets were set with the CG150, a current production model that uses a stamped frame, as the base model.

- (1) A 30% reduction in weight against the current stamped frame
- (2) A 30% reduction in production time against the production process for the current stamped frame
- (3) Identical performance (strength, stiffness, vibration) to the current stamped frame

3. Issues of Realizing Weight Savings and Technological Approaches

3.1. Status of Stamped Frames and Issues of Realizing Weight Savings

Figure 2 shows the shape of the frame for the CG150,

which is currently in production. In order to increase production efficiency, a mono-bone structure produced mainly using spot welding is employed. In this mono-bone structure, the structure from the head pipe to the seat rail is connected as a single unit. Spot welding is a high-productivity coupling method, but it necessitates the use of flanges for coupling, and the weight of the body frame therefore increases by the weight of the flanges. In the case of frames formed by mating stamped materials, because the yield from the material is the major focus in the shape of each individual part, optimization of shape in order to realize weight savings represents a challenge. Combining parts with good yield from material and determining how to use the flanges employed for spot welding structurally were the issues in realizing weight savings. Because of these issues, key points in design included realizing the appropriate direction of division for parts and realizing an efficient arrangement of cross-sections with consideration of the direction of load inputs. However, even when the flanges used for coupling are employed effectively in terms of function, an increase in weight produced by the flanges against a structurally optimized pipe frame is unavoidable. In order to achieve a weight reduction of 30%, it was therefore necessary to consider materials and plate thickness in addition to optimization of the structure.

3.2. Use of Thin, High-tensile Steel Plates and Associated Issues

The use of thin plates is an effective means of realizing weight savings. However, it was necessary to select materials with consideration of maintaining sufficient strength to resist severe use environments and to improve cost competitiveness. The authors therefore examined the potential for employing high-tensile steel plates, which are already used as a method of realizing weight savings in four-wheeled vehicles. Figure 3 shows a graph of material cost against material strength. Because material cost in relation to strength is low for both cold-rolled and hot-rolled high-tensile steel plates, efficient use of these plates is able to reduce material costs. It was therefore decided to employ thin, high-tensile steel plates, aiming to realize a 30% reduction in weight against the current stamped frame.

When the plate material is replaced with thin, high-



Fig. 2 Mono-bone frame of 2013 model year CG150

tensile steel plate, the arising issues are the decline in the frame stiffness, which is caused by the decreased thickness of the steel plate, and the tendency to have a larger stress, which is originated from the enlarged displacement. However, we thought those issues could be overcome by devising countermeasures on structures and the application of thin, high-tensile steel could be feasible.

3.3. Consideration of Frame Structure

In order to help ensure the necessary strength and stiffness using thin plates, a continuous closed cross-section structure was adopted in the main members of the frame. The required cross-section shapes were arranged for the assumed loading direction, and a structure to receive the load by a box shape was adopted. Figure 4 compares the cross-sectional shape of the main members for the current and developed frames. By contrast with pipe frames that use a uniform cross-section, in the case of stamped structures it is possible to freely modify the shape of the cross-section. Making use of this advantage, cross-section shapes were set that would make it possible to realize the necessary strength and stiffness for the required members. Further, the addition of rib structures (forming concave and convex areas on the

surface of the plates) made it possible to avoid a decline in stiffness of the surface with the use of thin plates.

3.3.1. Approach to realizing stiffness

The employment of a continuous cross-sectional shape would make it possible to realize the required stiffness despite the use of thin plates, but unless a closed cross-section was employed in the connections with other parts, stiffness would decline in these sections. Among the main frame members, the pivot plate uses a three-sided square shape for the fitting of the engine, making it an open section. A member was therefore employed in order to close the cross-section, helping to ensure stiffness. In addition, to prioritize the dimensional stability after welding, the connecting part between the main member and the seat rail adopted a uniting planes mutually. The connection used a square cross-section that helped to ensure stiffness, but when twisting loads were input from the seat rail, the cross-section was prone to deformation into a diamond shape, resulting in a decline in the stiffness of the frame. Two inner gussets were added to the interior of the main member in order to help prevent this deformation. The addition of the gussets helped to control the decline in stiffness due to deformation. Figure 5 shows the structure that closes the opening of the pivot section and the structure used in the main member to respond to deformation. The use of the frame structures described above and the application of thin, high-tensile steel plates made it possible to reduce the thickness of the plates used for the main members from 1.5 mm to 1.2 mm.

3.3.2. Approach to realizing strength

In attempting to realize weight savings, the area that represented an issue in terms of strength was the rear frame structure. The rear frame, in particular the seat rail, receives the load of the passengers, and also receives a high load input from the rear cushion. The use of thin plates increases the level of deformation in the member itself when it receives a load, and stress concentrates in the joint sections connecting the front and rear of the frame. It was therefore necessary to employ cross-sectional shapes that

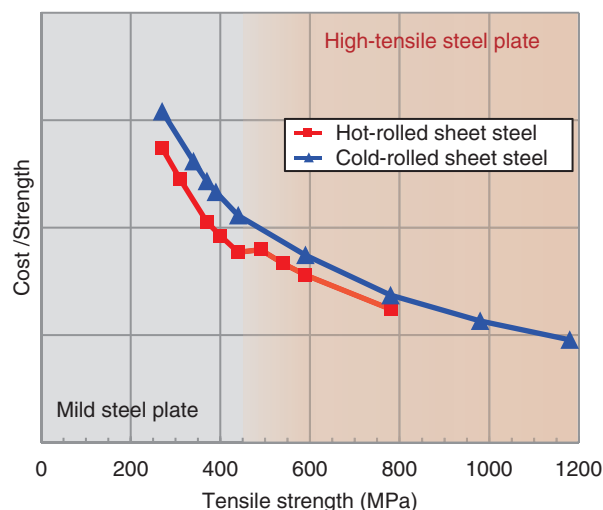


Fig. 3 Cost against strength of steel plate

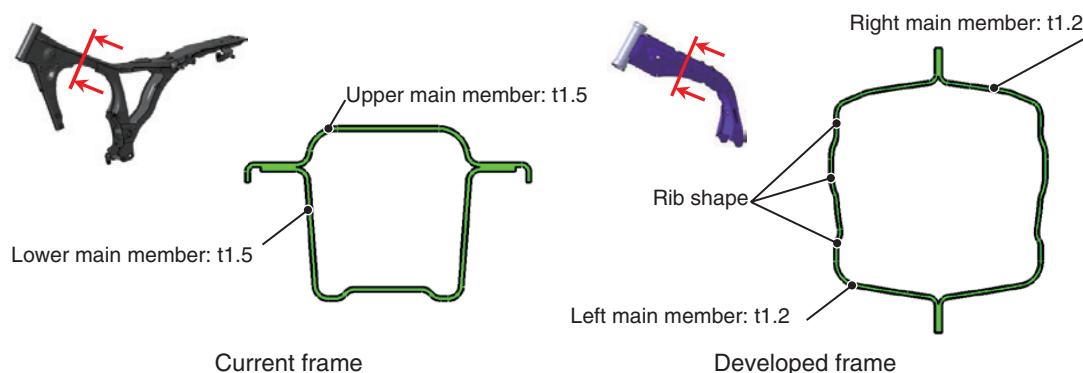


Fig. 4 Comparison of cross-sectional shapes of main members

would disperse this stress in the appropriate positions. The load input direction in the case of the seat rail was clear, with the up-down direction predominating. Due to this, a closed cross-section structure divided between left and right, which would increase the section modulus in the up-down direction, was adopted and welding flanges were positioned in the direction of load (the up-down direction). Figure 6 compares the cross-sections close to the area at which the seat rail supports the rear cushions in the current and the developed frames. By employing the appropriate cross-section structure in the necessary position in this way, it was possible to achieve a level of strength equivalent to that of the current stamped frame. However, because it is challenging to extend high-tensile steel during forming, there are limits to the depth of forming of the part, and it is challenging to realize the sectional modulus in the lateral direction when employing a structure with a left-right division. Members were therefore used in the appropriate

positions to connect the left and right sections of the seat rail in order to increase the robustness of the seat rail as a whole against load input in the lateral direction. The application of these measures and the use of 590 MPa-class high-tensile steel sheets have helped to enable the seat rail to receive loads efficiently, and made it possible to employ thin steel plates that reduce the thickness of the seat rail members from 1.5 mm to 1.0 mm.

4. Enhancing the Production Cycle: Issues and Methods of Realization

4.1. Conventional Stamped Frame Production Process

Figure 7 shows the elements of the welding process for the current stamped frame. The overall process is made up of three sub-assembling processes and a main assembling process. There are differences in the times necessary for the sub-assembling processes due to the composition of

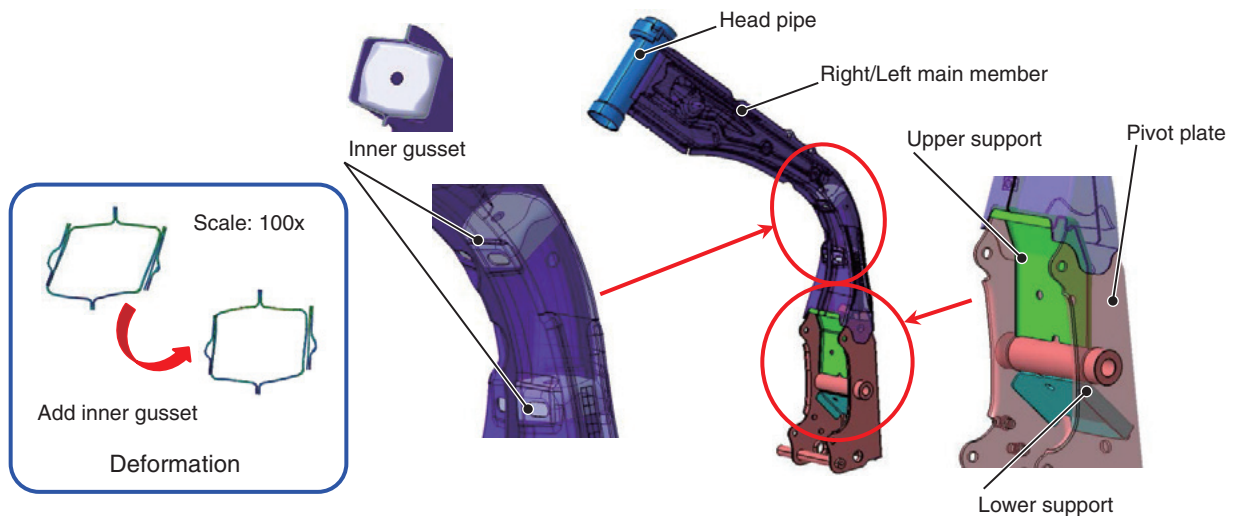


Fig. 5 Structure of main frame parts

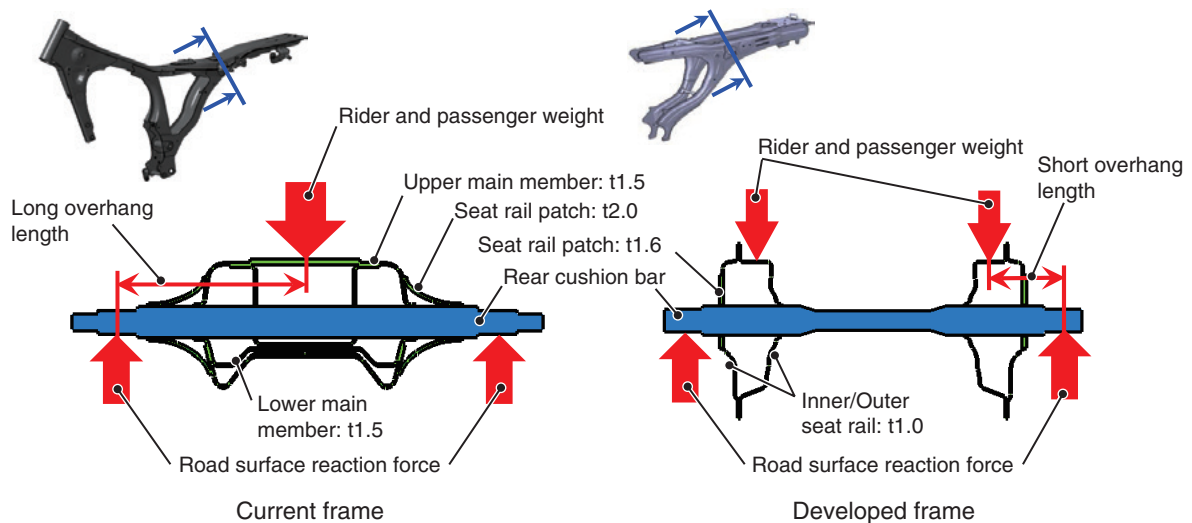


Fig. 6 Comparison of supporting area of rear cushion

the parts, and the time taken is determined by the longer processes. In addition, due to the shapes of the parts produced in the sub-assembling processes, the management and correction of the parts is not completed during these processes, and it is necessary to check the parts during the main assembling process. This means that second and third checks and correction work are necessary. Simplifying management and correction by standardizing process times is therefore an issue in realizing more efficient manufacture of frames in response to the need to increase production. Because the structure of the frame is strongly related to the shapes of the parts produced in the sub-assembling processes and the difference in the times necessary for their assembling, it was necessary to consider changes from the perspective of the frame structure in order to realize high-efficiency production.

4.2. Frame Shape: Changes and Issues

The current stamped frame uses a mono-bone structure in order to reduce the welding processes involved and increase the yield from the material. As indicated in the previous section, in order to respond to the production of an increased number of units, it was necessary to change the shapes of parts in the sub-assembling and main assembling processes to further rationalize production. The issues involved in doing so were resolved by using a frame with a divided front and rear structure, like a pipe frame.

Figure 8 shows the stamped frame with the divided front and rear structure. The front section comprises from the head pipe to the pivot plate. The rear section is made up of the seat rail and the sub-tube and cross-plate that support it. The issue in employing a divided front and rear structure is the increased complexity of the shapes of the parts and a decline in the yield from the material. Generally, the yield

from the material is high for frames that use pipes for their main framework. Draw-forming stamped frames have a low yield from material in comparison to pipe frames, but their productivity is higher. It was therefore essential to increase the yield as much as possible in order to maintain cost competitiveness while increasing production efficiency through the use of a stamped frame.

4.3. Increasing Yield from Material: Technological Approaches and Methods of Realization

Increased complexity in the shapes of parts is a factor in reducing the yield from the material employed. For stamped parts, rectangular shapes offer the highest yield from the material, making it possible to use material from the band without waste. If the shapes of the parts become more complex (no longer rectangular) when they are blanked, the yield from the material declines. It is possible to increase the yield from the material by reducing the size of the parts, but this increases the number of parts and also entails more coupling and production processes. When taking production efficiency into consideration, it is necessary not only to increase the yield from the material, but also to minimize the number of parts. In addition, because the frame parts

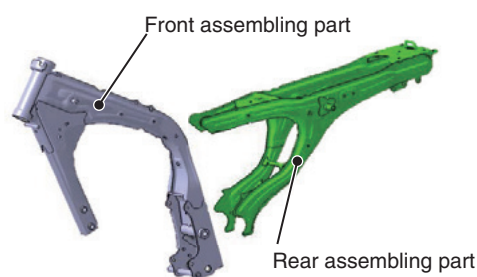


Fig. 8 Frame structure divided between front and rear

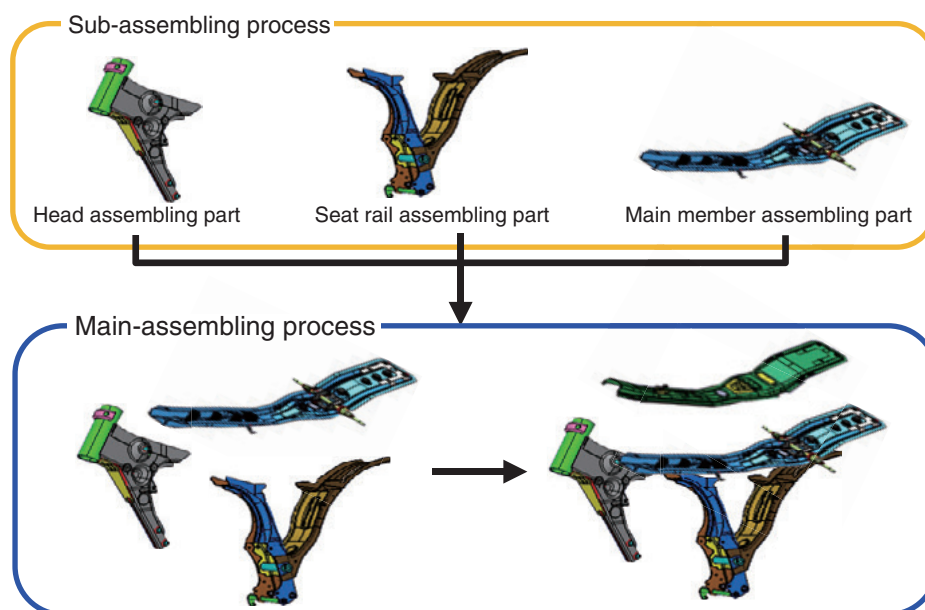


Fig. 7 Flow of welding process for manufacture of current frame

are shaped by draw-forming, it is necessary to remove the sections used to hold the parts during forming in a trimming process following the forming process. Because these trimmed sections are included in the material costs, this represents another factor preventing the yield from the material from being increased. The following two points were therefore focused on in order to increase yield:

- (1) The forming method of the products
- (2) The blanking process used for the material

4.3.1. Forming method of the products (Use of form-forming without need for trimming)

The application of form-forming, which by contrast with draw-forming does not necessitate trimming following forming, was examined as a means of increasing the yield from the materials. In draw-forming, the part is shaped by applying tension while inducing plastic deformation of the material; form-forming, by contrast, is a type of forming in which bends predominate. Figure 9 shows the draw- and form-forming processes. Form-forming offers a good yield from the material, but compared to draw-forming tends to form wrinkles in the parts, and its degree of freedom of shaping is low. To help prevent the occurrence of wrinkles, it is desirable to use shapes with a minimal difference between the length of the circumference during blanking and during forming. Mating of left and right sides was therefore used to produce parts shapes with lower forming

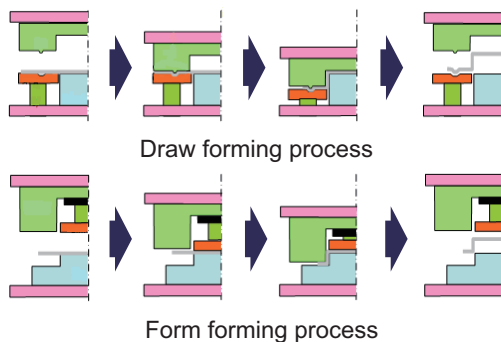


Fig. 9 Comparison of stamp forming process

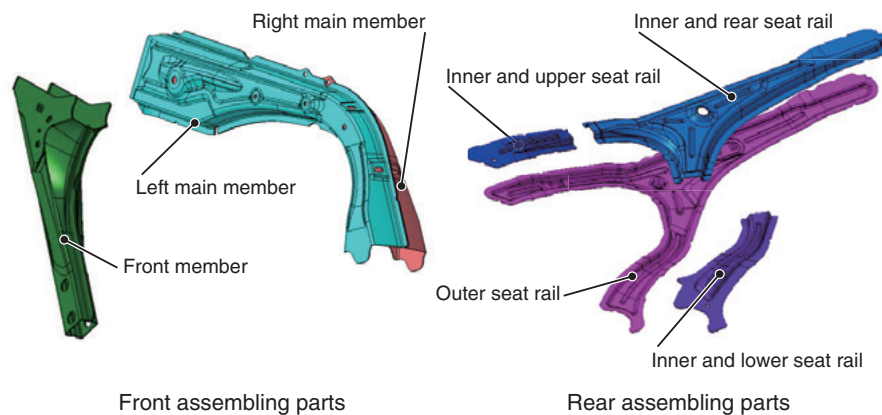


Fig. 10 Shapes of each stamped part

depth than conventional upper-lower mating in order to minimize difference in the length of the circumference as much as possible. A closed cross-section divided between the inner side and the outer side was employed for the seat rail. Figure 10 shows the shapes of the parts. When these parts were draw-formed, the yield from the materials was 53.5%. The application of form-forming, which does away with the need for trimming, increased the yield by 10 points, to 63.7%.

4.3.2. Blanking process (Simultaneous blanking of multiple parts)

Simultaneous blanking of multiple parts, in which small parts are positioned in the spaces left free by large parts, was employed in order to increase the yield from the material during blanking. The major issue in applying this manufacturing method was the necessity to standardize materials and plate thicknesses. In addition, the shapes of the parts being blanked simultaneously and the method of combining the parts are also important factors. The plate thicknesses for the front frame parts were therefore standardized at 1.2 mm and 1.6 mm, and for the rear frame parts at 1.0 mm. This arrangement of thicknesses makes it possible to blank multiple parts simultaneously, as shown in Fig. 11. Figure 12 shows the yield from the material

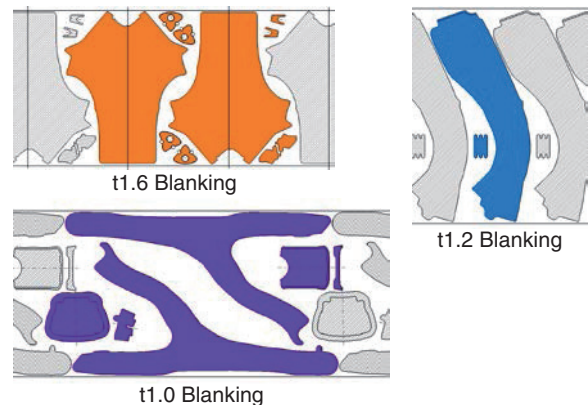


Fig. 11 Simultaneous blanking of multiple parts

for the current stamped frame and the yield rates obtained for the developed frame when simultaneous blanking of multiple parts and form-forming that does away with the need to trim the part are applied. As the figure indicates, the use of form-forming increases the yield rate by 3.5 points against the current stamped frame, and the addition of simultaneous blanking of multiple parts results in a further increase of 6.5 points. The application of the two methods discussed above increased the yield rate by 10 points against the current stamped frame, making it possible to employ a frame configuration divided between the front and rear while achieving a high yield rate.

4.4. Technologies for Increased Welding Efficiency

As indicated above, the issue in increasing the efficiency of welding was reducing the difference in the time necessary for each welding process. The time necessary for welding is the time for actual welding and the time for incidental operations related to welding. The latter category includes time for movement between processes and time for correction of distortion caused by welding. Spot welding is the main form of welding used in the manufacture of

the current stamped frame, but because MIG welding is necessary in numerous sections, a considerable amount of time is needed for incidental operations. In addition, the time needed for the fitting of vibration-absorbing rubbers to the interior of the frame during the main assembling process to help control ringing of the outer plates also adds to the time for processes incidental to welding. In response to these issues, the authors attempted to reduce the time needed for incidental processes through the application of the following three methods:

- (1) Reduction of welding points through integration of stamped parts;
- (2) Concentration of MIG welding; and
- (3) Reduction of number of procedures by doing away with vibration-absorbing rubbers.

4.4.1. Reduction of welding points through integration of stamped parts

The first point that was focused on in the current stamped frame configuration was areas in which left and right parts were mated and coupled by MIG welding. Figure 13 shows the shapes of the current and developed

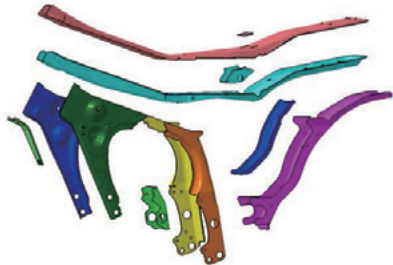
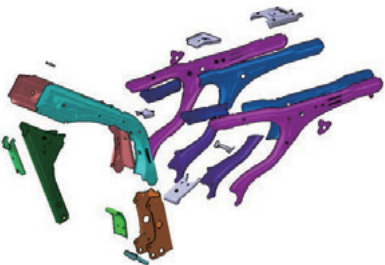
Material utilization		
Current frame body	Developed frame	
	Form forming	Form forming and simultaneous blanking of multiple parts
58.1%	61.4%	67.9%
		

Fig. 12 Comparison of material utilization

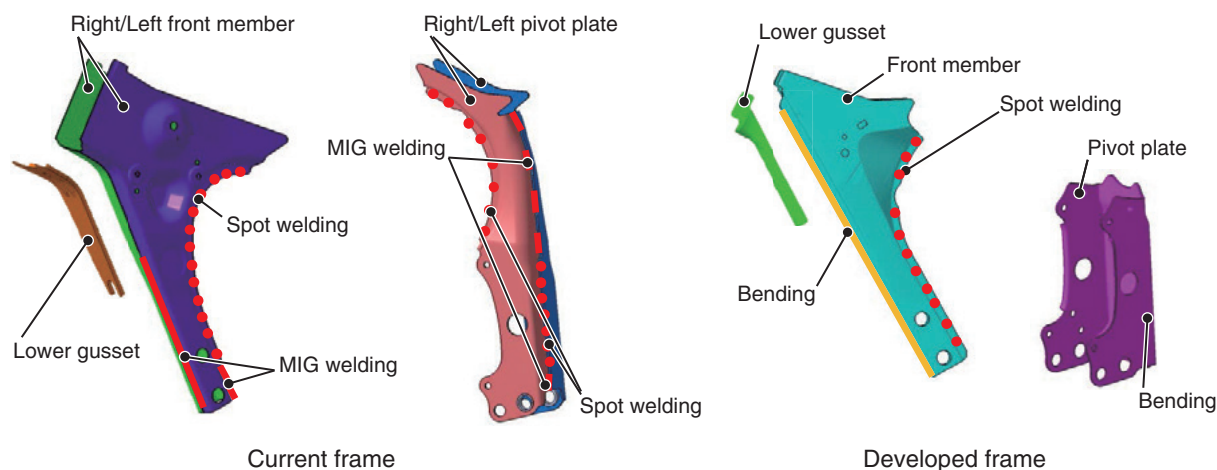


Fig. 13 Structural comparison of integrated parts

parts and the welding points employed. In current parts, the front member is formed with a left-right division; the two sides are connected by MIG welding at the front and spot welding at the rear. In addition, the pivot plate is coupled using spot welding at the front and MIG welding and spot welding at the rear. The potential for doing away with MIG welding and reducing the number of points for spot welding by integrating these two sections in the forming process was investigated. Because the frame uses a structure divided between the front and the rear, it was possible to reduce the size of the pivot and realize a simple three-sided square cross-sectional shape by extending the main member close to the pivot. The front member was integrated through the use of a UO bend. The UO bend is a technique used in the forming of pipes and similar products, in which a flat steel plate is given a U-shaped cross-section in a first procedure, following which the open ends are closed in a second procedure in order to create an O-shaped cross-section. In the present case, the technique was used to create closed cross-sections in integrated stamped parts. The bend employed is a two-dimensional curve, and it is essential that the section to be bent is straight. However, if the section of the front member to be bent is straight, the section that contacts the head pipe becomes pointed, and stress concentrates in this section. The use of a lower gusset to block this sharp section has helped to prevent stress from concentrating and formed a structure that is able to resist load inputs. This made it possible to integrate each of the parts whose new shapes are shown in Fig. 13, doing away with MIG welding and reducing the number of spot welding points by 15.

4.4.2. Concentration of MIG welding

Frames that are manufactured mainly using spot welding are suited to high-speed production. However, due to the limitations of shunting, spot welding is unable to concentrate coupling points in a narrow area. MIG welding was therefore applied to restricted areas of the points at which a closed cross-section was being welded, where stress would be concentrated; the points at which bars or pipes were being coupled; and the points at which a continuous coupling was desired in order to help ensure stiffness (Fig. 14). While the welding length increased at

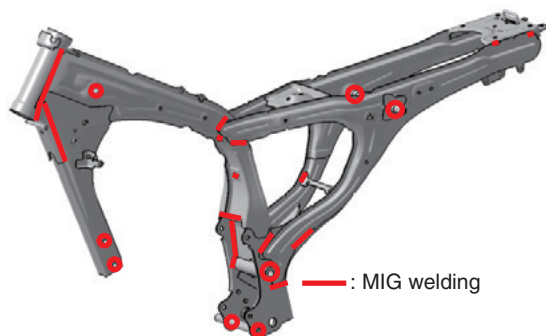


Fig. 14 Points for application of MIG welding

certain points, this helped to prevent complexification of the welding process, and increased production efficiency. In addition, the use of plate members as cross members made it possible to couple them using spot welding.

4.4.3. Reduction of number of procedures by doing away with vibration-absorbing rubbers

Because stamped frames are composed of large stamped parts with many flat surfaces, the vibration of the engine causes their surfaces to vibrate like the skins of drums, resulting in ringing in the outer plates. In the current stamped frame, this surface vibration was controlled by the application of vibration-absorbing rubbers to the interior of the body frame, controlling ringing in the outer plates. To make it possible to do away with these vibration-absorbing rubbers, it would be necessary to control surface vibration by means of cross-section shape, the makeup of parts, and structure. Ringing in the outer plates was therefore controlled by reducing the surface area of the members making up the frame and increasing the surface stiffness of each of the members. The use of a structure divided between front and rear for the body frame and a structure divided between left and right for the seat rail in the new frame reduced surface area by 15% against the current frame. In addition, the use of concavities, convexities and curves in the various sections helped to do away with large planar sections, and increased surface stiffness. Figure 15 shows the vibration-absorbing structures used in the current frame, and the concavities and convexities added to various sections in the developed frame. The vibrations were suppressed by installing plates within the parts if there were difficulties in applying reinforcing indents or extrusions because of the necessity for the part to be a flat plane shape due to a requirement in production processes. Figure 16 shows this configuration. The application of these methods has controlled surface vibration structurally, making it possible to entirely do away with the vibration-absorbing rubbers.

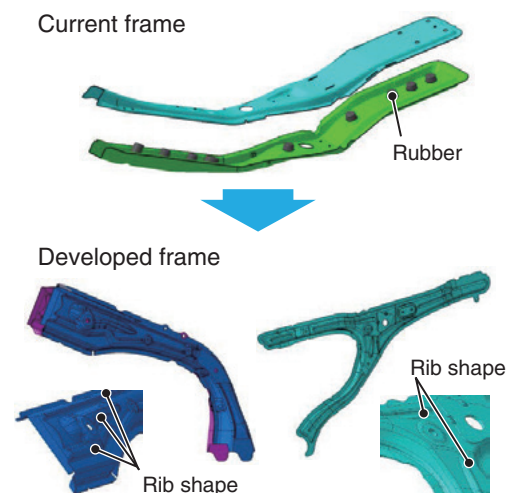


Fig. 15 Rib structure for suppressing surface vibration

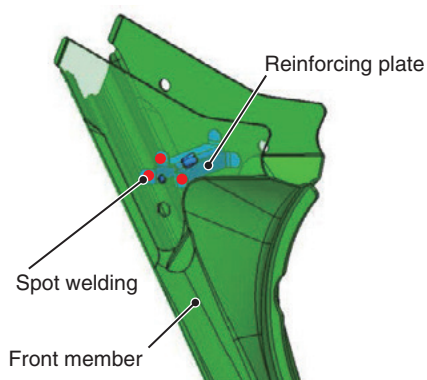


Fig. 16 Internal structure for suppressing surface vibration

5. CAE Verification of Unit Performance

Figure 17 shows the shape of the developed frame. Unit performance for this frame was verified using CAE. A solid model was used in stiffness and strength analyses, while a surface model was used in a vibration analysis.

5.1. Verification of Stiffness

Figure 18 shows a comparison of stiffness values

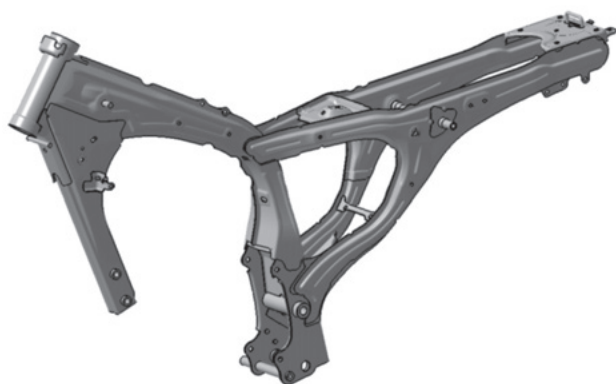


Fig. 17 Shape of developed frame

measured with the swing-arm pivot fixed and a lateral load input to the front axle for the current and developed stamped frames. The graph shows lateral stiffness and torsional stiffness with values for the current frame defined as 1. Figure 19 shows deformation diagrams at the time that the measurements were taken. As the comparison of stiffness values indicates, results for the developed frame are almost identical to those for the current frame.

5.2. Verification of Strength

Figure 20 shows a stress distribution diagram produced when the maximum load projected for running on a rough road is input to the rear cushion mounts. As this diagram indicates, the load is dispersed with a good balance through the entire member, with no local concentrations of stress.

5.3. Verification of Reduction of Ringing in Outer Plates due to Vibration

Figure 21 shows a comparison of the vibration level with and without rib reinforcement, focusing on an area with a large cross-section and a broad surface area for sound to radiate from. The figure on the left shows results for the developed frame with rib reinforcement. The figure on the right shows results for an analysis of the same frame without ribs, conducted to provide a comparison. The red

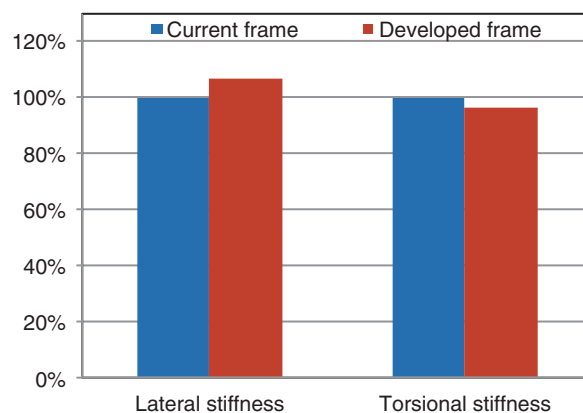


Fig. 18 Comparison of stiffness values

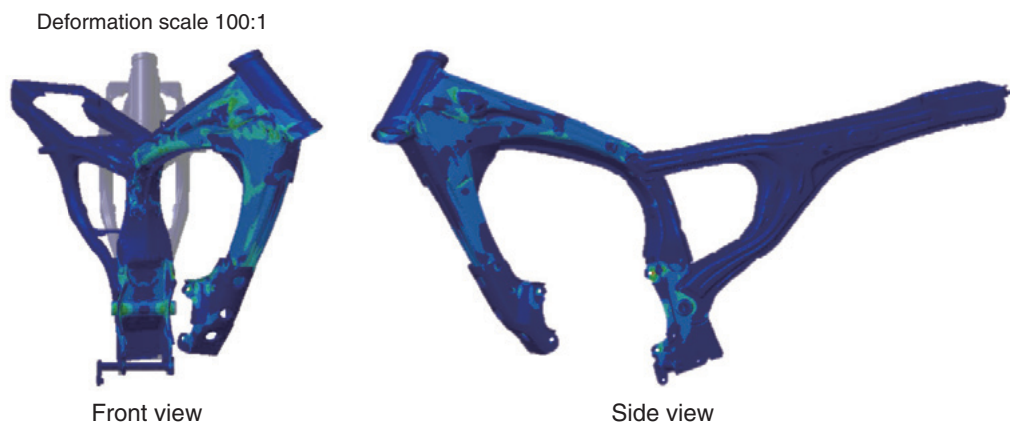


Fig. 19 CAE deformation diagram showing stiffness

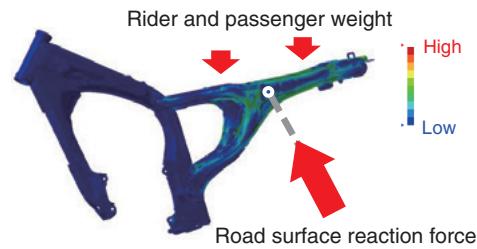


Fig. 20 CAE stress distribution assuming running on rough road

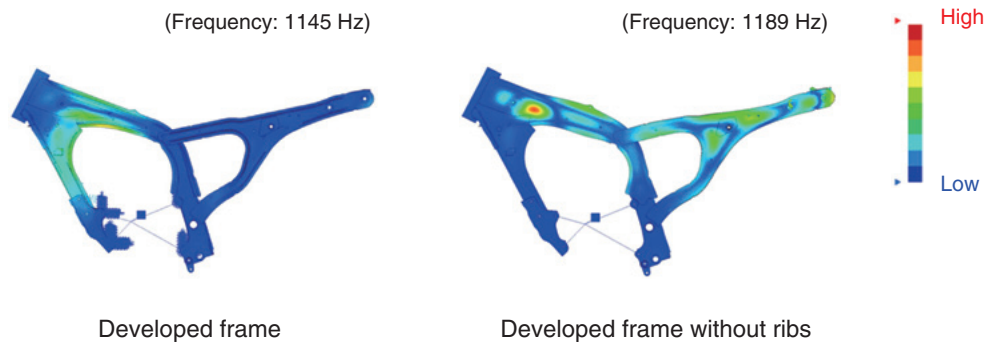


Fig. 21 Confirmation of vibration reduction by eigenvalue analysis of mode shape

areas in the figures show the areas of high amplitude. The results show that while there is significant local vibration of the outer plates in the frame without ribs, in the developed frame the ribs help ensure surface stiffness, controlling ringing in the outer plates produced by surface vibration.

6. Confirmation of Effects

6.1. Weight Reduction Effect

Figure 22 shows the weight reduction effect dividing the current and developed frames into the front frame

section and the rear frame section. While the current stamped frame did not employ a structure divided into front and rear, the comparison was conducted with the current frame divided based on the concept of the developed stamped frame. The results of the comparison show that weight reductions of 2 kg were achieved in both the front and rear frames. The result achieved for the rear frame in particular (-33%) indicates that reducing the thickness of the plates had a significant effect. The developed frame is four kilograms lighter than the current frame, at 10 kg to 14 kg, realizing the target for a 30% reduction in weight.

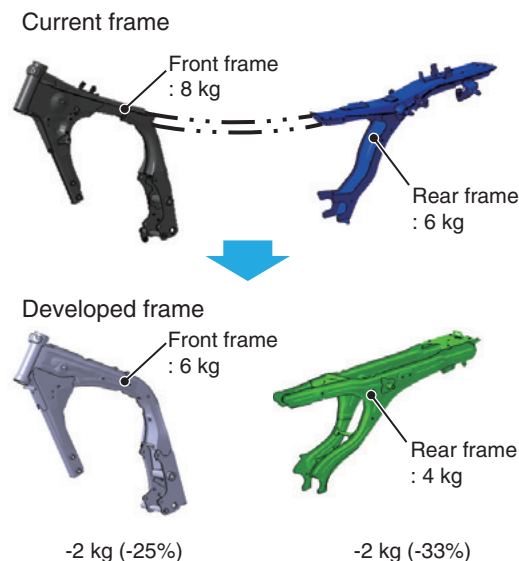


Fig. 22 Weight reduction effect and structural comparison

6.2. Effect of Reduction of Time for Manufacturing Procedures

Figure 23 shows the order of coupling in the sub-assembling and main assembling processes for the frame using the methods described in Chapter 4. Figure 24 compares the length of MIG welding and the number of spot welding points for the current and developed methods, and Fig. 25 compares process time for the current and

developed methods. In the developed frame, the total MIG weld length has been reduced by 200 mm, and the replacement of MIG welding by spot welding and other initiatives has reduced the time for incidental procedures by one-half. As a result, while the time for actual welding is the same as for the current stamped frame, the process time is reduced by 30% against the time for the current stamped frame considered as 1.

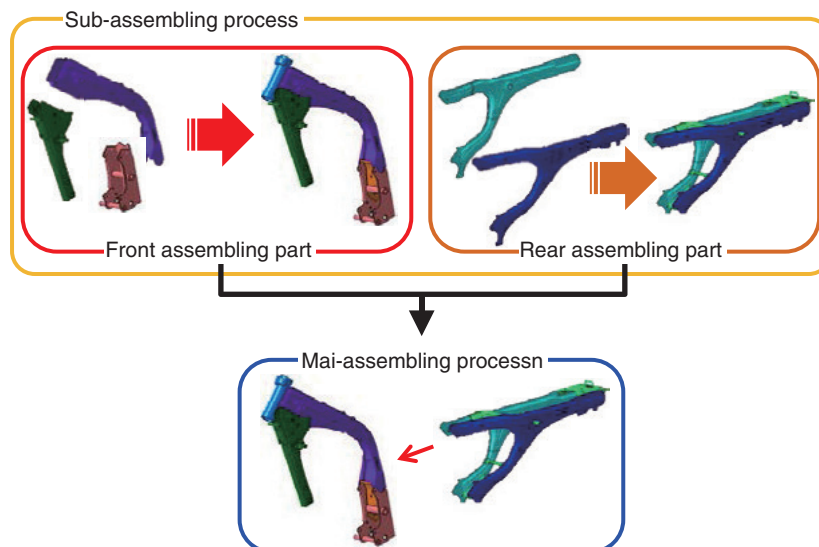


Fig. 23 Flow of welding process for manufacture of developed frame

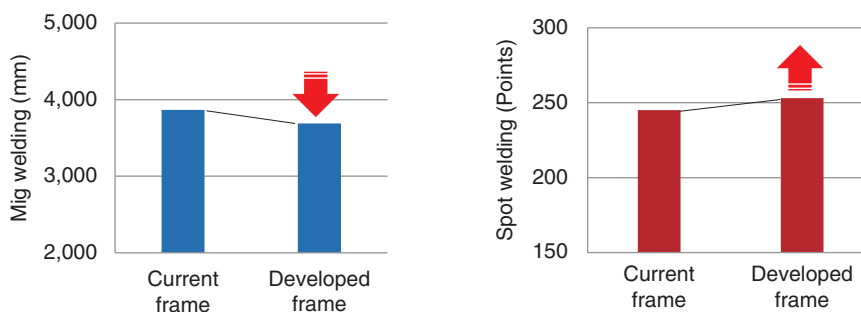


Fig. 24 Length of MIG welds and number of spot welds

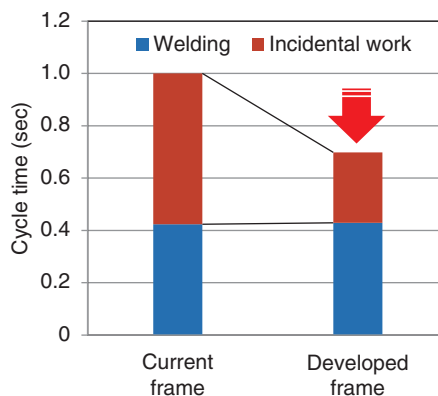


Fig. 25 Reduction of process time

7. Conclusion

A lightweight and high productive efficiency stamped frame for small motorcycles produced in large numbers was developed. The following are the salient points of the development.

- (1) Using thin, high-tensile steel plates, stiffness was realized by means of a structure offering a continuous closed cross-section. A closed cross-section divided between left and right, employing a structure having flanges for welding at the upper and the lower portions of the parts, was used for the seat rail; these sections were connected by cross-plates to help ensure strength. By means of these methods, while the developed frame is stamp-formed like the current frame, the plate thickness of the main frame sections has been reduced from 1.5 mm to 1.2 mm, and of the seat rail from 1.5 mm to 1.0 mm, realizing a weight reduction of 4 kg.
- (2) The application of simultaneous blanking of multiple parts and form-forming that does away with the need for trimming has increased the yield rate from the material, and made it possible to realize a front-rear divided structure in a stamped frame.
- (3) Integrated forming of parts and concentration of MIG welding have made it possible to reduce the length of MIG welds and replace MIG welds with spot welds.
- (4) The use of a front-rear divided structure in the frame and a left-right divided structure in the seat rail has reduced surface area by 15%; this, in addition to the use of ribs to reinforce surface stiffness, has made it possible to do away with the vibration-absorbing rubbers previously used.

These innovations have reduced weight by 30% and process time by 30% against the current stamped frame.

References

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