Invited Special Paper

Laser Welding Application in Car Body Manufacturing

H. O. Shin, I. S. Chang and C. H. Jung

Abstract

Laser welding application for car body manufacturing has many advantages in the stiffness and the lightness of vehicle, the productivity of assembly line, and the degree of freedom in design. This presentation will express the innovation of car body manufacturing including parameter optimization, process modeling, and system integration. In this application the investment for systems was cut down dramatically by real time switching over the laser path between two welding stations. Points of technical discussion are as follows; optimization of parameters such as laser power, robot speed and trajectory, compact and useful design of jig & fixture to assure welding quality for 3 sheet-layer zinc-coated steel, system integration between 4kW Nd:YAG laser device and the other systems, on-line real time welding quality monitoring system, perfect safety standards for high power laser, minimization of consumption costs such as arc lamp, protective glass for optic, etc.

This application was successfully launched mass production line in 2001. The laser-welded line of side panel consists of 122 stitches totally. And the length is about 2.4m.

Key Words : Laser welding, Nd:YAG laser, Parameter optimization, System integration.

1. Introduction

Most automotive companies make use of resistance spot welding in order to assemble car body. Generally car body has almost 5,000 spot welding points. Even though spot welding has been progressed for last 60 years, there were some limitations in upgrading production line. So instead of conventional spot welding it is time to start a new technology for the future.

Laser welding has many advantages in car body manufacturing. Thanks to fast speed, it can reduce the number of welding station of car body assembly line. And also with non-contact & one-side approach, it is possible to design various car body structures. Maybe laser welding can free car designers from box structure for spot welding. It means that we can reduce the weight of body by optimized design. There is another reason that we cannot help choosing laser welding. In order to increase strength of body and decrease weight of body automotive companies have developed new technologies such as hydrofoming, aluminum & magnesium alloy, plastic. We don't find perfect joining method, which can join hydroforming parts and these materials except laser welding. So we have developed laser welding for car body for a long time. But laser welding was not sufficient to substitute for spot welding. Because it is very difficult to assure welding quality of zinc-coated steel in mass production and it needs more money than spot welding[1]. This study shows the solution to overcome difficult problems.

2. Parameter Optimization

Laser welding can make flexible trajectory because it is a non-contact method as compared with conventional welding. In order to realize superior merits of laser welding we have tested a great number of welding patterns shown at Fig. 1 and selected the best pattern[2].

Laser welding system based on Nd:YAG laser consists of various parameters such as laser power, velocity of 6-axis industrial robot, focal position of laser beam, the gap between sheets, and the number of sheet layer. Parameters are shown in Table 1.

After finishing the experimental design through Taguchi method, we made use of experimental device shown in Fig. 2.

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Table 1 Level of welding parameters

Fixed value	Level 1	Level 2
Steel type of panel	Mild	Zinc-Coated
Sheet Layer	0.7 + 0.7	1.2 + 1.4 + 0.7

Variable (2 sheet-layer)	Level 1	Level 2	Variable (2 sheet-layer)	Level 1	Level 2
A. Laser power (kW)	2.0	2.7	A. Laser power (kW)	3.0	4.0
B. Velocity (mm/s)	60	100	B. Velocity (mm/s)	28	35
C. Focal Position (mm)	0.0	4.0	C. Focal Position (mm)	0.0	1.0
D. Gap between panels (mm)	0	0.2	D. Gap between panels (mm)	0	0.2+0.2

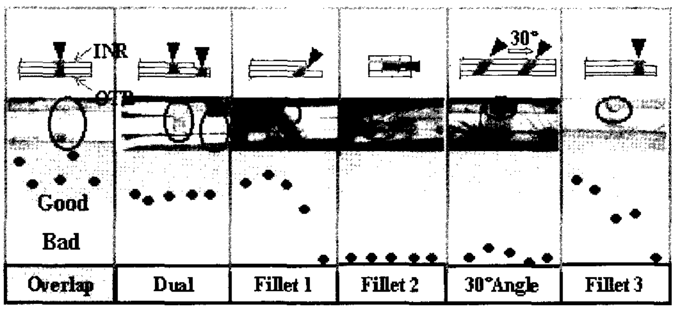

Fig. 1 Ideas of welding pattern

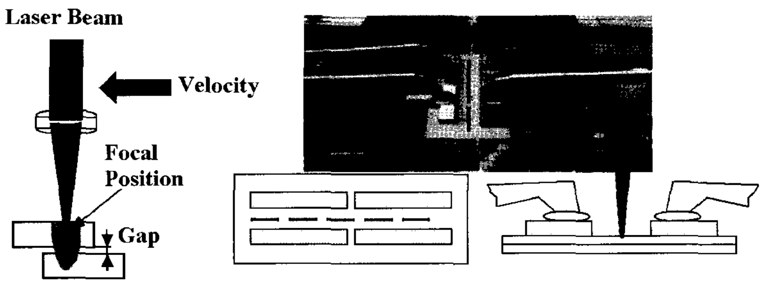

Fig. 2 Setup of the experimental system

As the result of interaction between factors, we can know that there is an independent relationship between A(Laser Power) and B(Velocity) and there are dependent relationships between A(Laser Power) and D(Gap), between B(Velocity) and D(Gap), in Fig. 3. Taguchi L8 orthogonal array in Table 2 was designed in consideration of interaction between factors.

Equation (1) is S/N ratio for performance of Lager-the-better in order to obtain robust factor level which minimizes the effect of noise and maximizes the strength of welding[2)].

$$S/N \text{ ratio} = -10\log_{10}\Sigma(1/y_i^2)/n \quad (1)$$

We calculate variance analysis of overall, interaction, and error from S/N ratios. And contributions(ρ) of factors are defined by equation (2) ~ (4).

$$\rho_{factor} = (S'_{factor} / S_{overall}) \times 100 \quad (2)$$

$$\rho_{interaction} = (S'_{interaction} / S_{overall}) \times 100 \quad (3)$$

$$\rho_{error} = \rho_{overall} - \Sigma\rho_{factor} \quad (4)$$

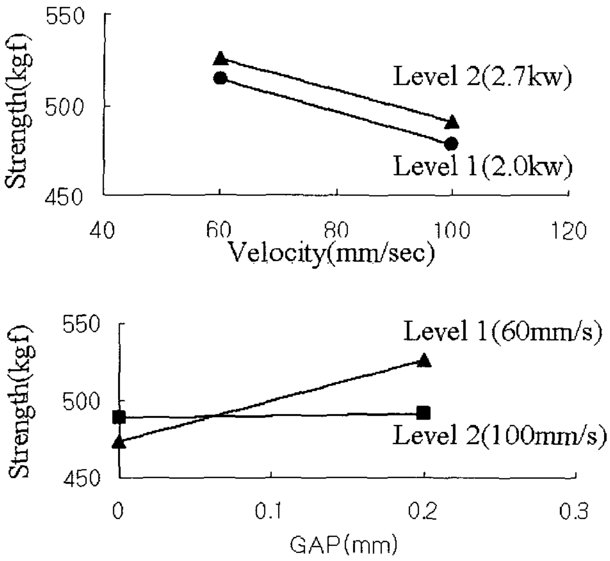

Fig. 3 The interaction between A and B, B and D

Table 2 Taguchi L8 orthogonal array

Expt No	Factor						
	A	B	C	D	AD	BD	-
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	1	1	1	1	2
6	2	1	1	2	2	2	1
7	2	2	2	1	1	2	1
8	2	2	2	2	2	1	2

As the result of analysis, the most effective factor is B(Velocity), 51.6%. The next things are A(Laser Power), 25.8% and C(Focal Position), 15.8%. And then as the result of optimizing the factors which can minimize the effect of noise and variability simultaneously, the best conditions are level 2(2.7kW) of A(Laser Power), level 1(60mm/s) of B(Velocity), and level 1(0.0mm) of C(Focal Position). In the case of this parameter optimization, the expected result of welding strength shows the expected value is 27% higher than the non-optimized. In order to make the standards of welding specification we have tested 22 combinations of sheets which were applied to laser welding in mass production.

3. System Overview

It is very difficult to design the system based on laser device because of its specialty. In the plant of car body manufacturing the process of laser welding to assemble car body has different configuration from the process of resistance spot welding. The laser welding system consists of 6-axis industrial robot attached optic head which can focus laser beam irradiated from laser source, 4kW Nd:YAG laser device, beam delivery system which can transmit laser beam using fiber cable from in-coupling of laser device to out-coupling of optic head, jig & fixture system which can control the gap tolerance between sheets in order to assure welding quality, on-line welding quality monitoring system, and common communication network protocol to integrate systems consisted of different communication network. In order to perform the best welding we need the selection of device and optimal design for system.

In order to increase productivity of laser welding, we designed stitch pattern, which has welding distance of 20mm and moving distance of 30mm repeatedly. So welding robot needs several requirements ; the performance of acceleration and deceleration in very short pitch of stitch pattern, the performance of uniform velocity in 20mm of welding distance to preserve welding quality from outside disturbances, the accuracy of trajectory and repetition to maintain focal position of laser beam within the tolerance that can do good welding. We tested outstanding industrial robots from several makers, but we could not find perfect robot which satisfied all conditions. Therefore we selected the best robot among them based on Fig. 4. And also useful sequence program was developed to solve the problem that the start and end points of welding line had bad quality due to the limitation of robot dynamics.

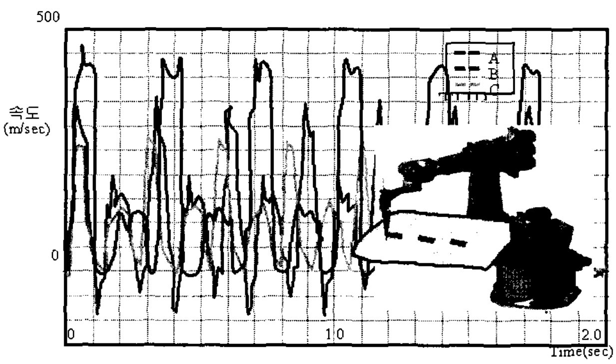

Fig. 4 The robot performance of velocity

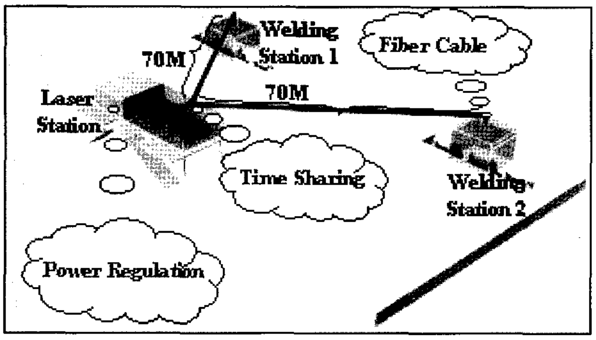

Fig. 5 The layout of system

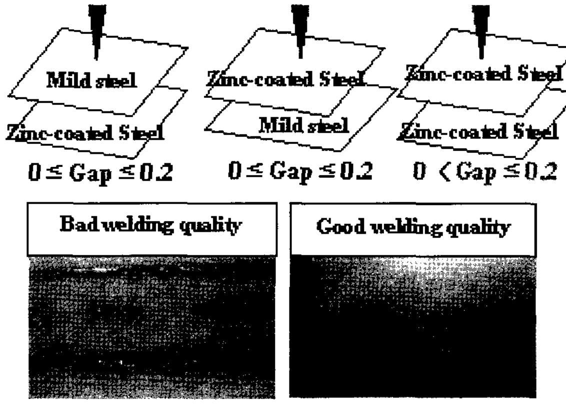

Fig. 6 The influence of gap between sheets

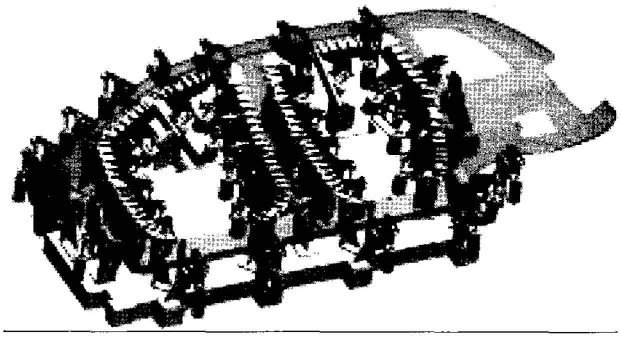

Fig. 7 Jig & fixture for controlled gap

Nd:YAG laser has a good merit to transmit laser beam through fiber cable. Because most automotive factories are full of many kinds of facilities, we cannot help using this merit. So we installed the laser device far away from the welding station. Fig. 5 shows the layout how to install laser welding system. There are two welding stations of four robots and one laser station of two laser devices. As shown in Fig. 5, laser beam was generated by laser device of 4kW Nd:YAG and transmitted by fiber cable(70m) from laser station to welding station. After that, side panel was welded by laser beam, which was controlled as time-sharing. At that time, laser device needed good performances because it had to rapidly control the sequence of time-sharing all day long.

Mentioned above, the geometry of welding joint was chosen as overlapped joint. According to another reports[3], there were two contrary problems. In the case of wider gap than tolerance between sheets, it gave rise to undercut or separation of welded area due to non-contact approach of laser welding. On the contrary, in the case of zinc coated steel, no gap between sheets gave rise to porosity and poor surface quality. The zinc coatings at the interface of two-coated sheets vaporize during welding because the boiling point of zinc gas(900 ~ 910℃) is lower than the melting point of steel(1400 ~ 1500℃). If there is no vent to escape zinc gas, zinc vapor cannot help leading to expulsion of molten metal. The present solution to these contrary problems is to control the gap between sheets. Usually the gap is in range of 0.1 and 0.2mm, depending on the type of steel and coating, the thickness of sheet and coating. Fig. 6 shows the results of welding quality, respectively. It means that jig & fixture to control the geometry between sheets has to assure a little gap instead of no gap. It is very difficult to maintain controlled gap in mass production line. Fig. 7 shows the jig & fixture applied to special idea

Welding quality of conventional welding has been checked by inspection of post-welding. But in laser welding it is possible to measure as on-line real time automatically whether welding quality is good or not[4]. Generally as laser welding starts, the process radiation reflected back through the welding optics and fiber cable was mapped on the sensor mounted inside the laser device. A defined spectral range of the process radiation conducted back through the optical waveguide was optically filtered and transformed into an electronic signal by means of detector that was proportional to the radiation capacity of the process radiation. Then this signal was fed to the computer through signal processing device after pre-amplification and filtering. After that, process signal evaluated through software was displayed as specific output. On the basis of real signals in good quality, reference signals that divide into average signal, signals of lower and upper limit were selected by analyzing correlation of tolerances between quality and signal. So real signal exceeded limit value in bad quality as shown in Fig. 8. After finishing 1 welding cycle, the stored welding data was recorded as files to establish database.

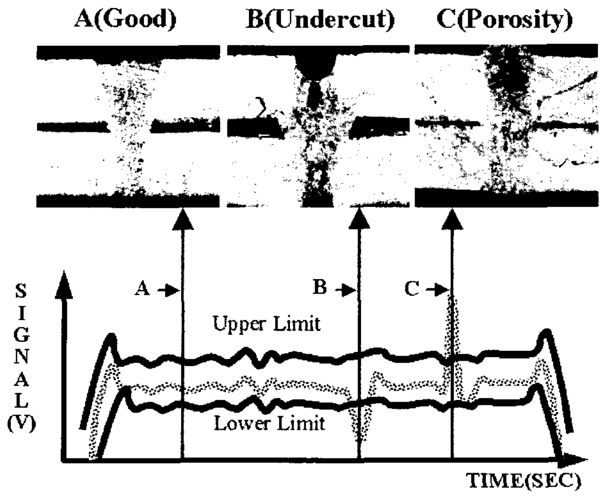

Fig. 8 The principle of inspection for laser welding

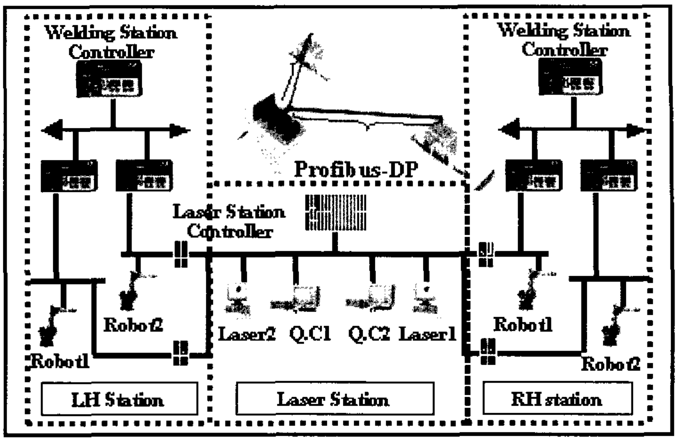

Fig. 9 The configuration for system integration

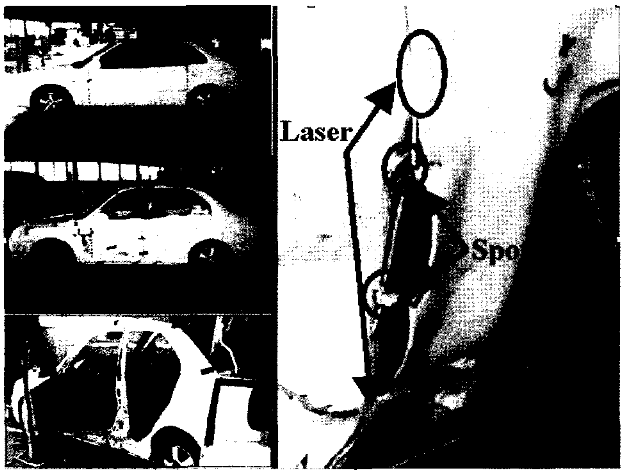

Fig. 10 The result of collision test by side impact

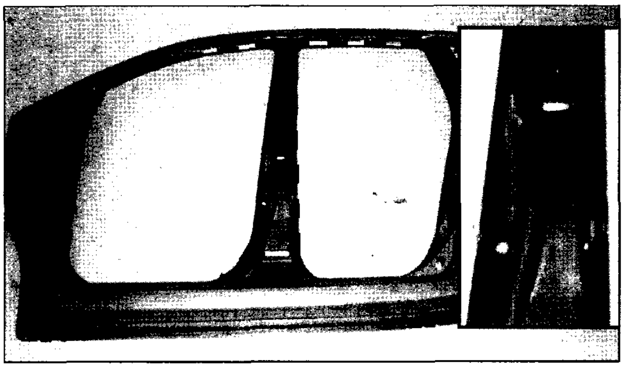

Fig. 11 The overview of laser-welded line in side panel

4. Results

To prove that laser-welded body can obtain higher performance than spot-welded, 5 car bodies were carried out necessary tests including collision. As the result of test, laser-welded car satisfied the requirements of safety and performance as shown in Fig. 10.

In 2001 two new models assembled by laser-welded side body panel have launched mass production. The total length of laser welding is about 2.4m and the combination of welding parameter consists of 26 conditions. Fig. 11 shows laser-welded part.

5. Conclusion

The last goal of this study is that manufacturing technology in car body plant exchanges the solution based on resistance spot welding for the solution based on laser welding. The conclusions can be summarized as follows:

1. In laser welding, it is difficult to optimize parameters because it is more sensitive than the other welding. On testing many combinations of sheets by Taguchi method, we have established database for laser welding conditions successfully.

2. Welding quality depends on performance of system including robot, laser device, jig & fixture, and

communication network. At first, each system has been designed for best performance respectively, and then all systems have been integrated by robust design of hardware and software coping with full operation all day long.

3. The result of vehicle tested has proved the performance of laser-welded body to be satisfied with safety criterion.

4. On-line automatic quality monitoring system has improved the level of quality management.

Since this report has demonstrated a small successful step for this goal, laser welding will be used to a greater extent in the future.

References

1. W. M. Steen : Laser material processing, 2nd Edition, *Springer*, (1998), pp. 108-144
2. M. S. Phadke : Quality engineering using robust design, *Prentice Hall*, (1989), pp. 97-132
3. M. G. Forrest and W. A. Marttila : A study of effect of laser welding process parameter variation on weld quality for Zn-coated thin auto body sheet material, *Automotive Laser Applications Workshop*, (1996)
4. J. Mommsen and M. Stuermer : Recent development in process monitoring and data management for laser welding, *European Automotive Laser Application*, (2001)