Analysis and Research on Mismatch in Tailored Blank Laser Welding

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***Abstract* – Mismatch is an important quality evaluation standard in Tailor Welded Blanks. The control of mismatch, especially for thinner blanks, is a difficult technique in Tailored Blank Laser Welding process. In this paper, the production and control of mismatch is studied based on a Tailored Blank Laser Welding system. The origins of the mismatch are obtained after numbers of experiments: the deformation of the blanks before welding, the intensity of the clamping force, the uniformity of the clamping force, the deformation of the clamping beam, the flatness error of the based platform and the welding process. A mathematical model is established according to the analysis of the origins producing mismatch. Experimental results indicate that the model provides an effective theory in increasing welding quality.**

***Keywords* – Mismatch, Tailored Blank Laser Welding, Origins of the mismatch, Mathematical model for mismatch**

I. Introduction

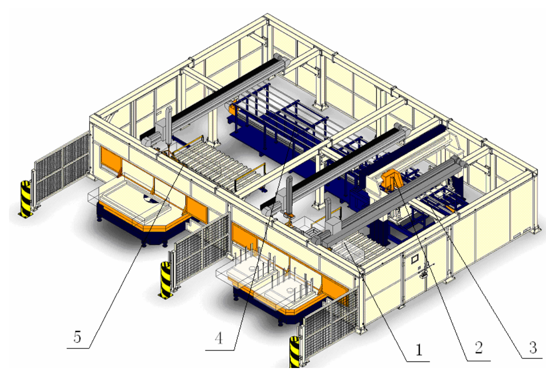
Laser manufacturing is a modern process technique with the advantages of deep weld penetration and minimizing heat inputs [1-3]. Tailored laser welding technology has become an important manufacturing process for automobile industry. Tailor welded blanks are defined as two or more sheets of blanks with same or different mechanical properties or surface coatings welded together by laser before stamping [4]. With the development of this technique, the focus attention has been changed into solving the problems of reducing automobile weight, oil consumption and air pollution from the initial application of wide blanks with equal thickness by laser welding. Tailor welded blanks has become a hot issue in the automobile industry and steel industry for its high quality, high profit and low cost of production[5], [6].

Laser welding is superior to general weld method, but it is very strict with the welding quality especially mismatch. Mismatch requirements are driven by product requirements as well as process requirements, such as die settings and weld strength requirements in stamping operations. In order to obtain quality stamped panels, tailor welded blanks should be sufficiently aligned so that no point along the weld seam is offset by greater than 15 percent below flush or 20 percent above flush of thickness of the thinner member.

Mismatch will be studied in detail in this paper. First, origins of mismatch are analyzed based on several theoretical analyses and measurements, then Mathematic model is built to predict mismatch and last experiment is carry out to prove the efficiency of the model.

II. Structure of the System

Fig. 1 shows the view of the Tailored Blank Laser Welding system which is made up of several units, including load unit, positioning unit, welding unit, ejector unit, unload unit and control unit.



1. Load unit 2. Welding unit 3. Positioning unit 4. Ejector unit 5. Unload unit
Fig.1 Tailored Blank Laser Welding system

III. Origins of Mismatch

A. Definitions

Mismatch is defined as when two or more sheets of blanks with same or different thickness welded together, the two blanks should be sufficiently aligned so that no point along the weld seam is offset by greater than 15 percent below flush or 20 percent above flush of thickness of the thinner member (Fig.2) [7].

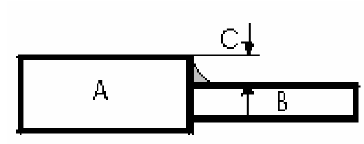


Fig. 2 Define of mismatch

B. Analysis of the Origins Producing Mismatch

The structure of the clamping set and the deformation of the blanks are the main reasons for mismatch. There are six factors affecting the production of mismatch: the deformation of the blanks before welding, the intensity of the clamping force, the uniformity of the clamping force, the deformation of

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the clamping beam, the flatness error of the based platform and the welding process.

Fig. 3 is the clamping set of the Tailored Blank Laser Welding machine. It has two functions: guaranteeing the position precision of the blanks and controlling the deformation of the blanks.

Fig. 3 Clamping set

1) Deformation of the Blanks

The deformation of the blanks is the direct factor for mismatch. The blanks to be welded may be deformed partially during feed preparation, storage and transportation. The deformation of the thin blank sheet has the characteristics of complexity and pluralism. There are two typical basic deformations shown in Fig. 4 after investigation: deformed around X and Y axis respectively. All the deformations of the blank sheets can be composed of two basic deformations. The deformation of the welding edge will not disappear, because there is about 10mm projecting edge of the blank sheet when clamped, the deformation of the welding edge will produce mismatch. We can use mathematical method to obtain the deformation around X axis, and finite element analysis method to find the deformation around Y axis.

Fig. 5a shows the deformation around X axis before clamped. From Fig. 5b we can see that the deformation in clamped area disappears, but the deformation of the projecting edge of the blank sheet still exists. The deformation can be described as:

$$h = R - \sqrt{R^2 - l^2} \tag{1}$$

where h is the deformation of the blanks around X axis, R is the radius of the deformation, and l is the length of the projecting edge.

Mismatch produced by deformation of the blanks can be described as:

$$M_{bd} = M_{bdx} + M_{bdy} = R_x - \sqrt{{R_x}^2 - l^2} + M_{bdy} \tag{2}$$

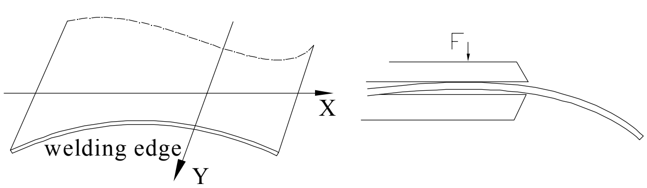
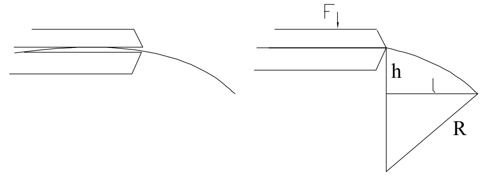


Fig. 4 Two typical basic deformations



a. Before clamped b. After clamped

Fig. 5 Deformation around X axis before and after clamped

2) Intensity of the Clamping Force

The intensity of the clamping force is an important factor in controlling mismatch. Small clamping force can not make the deformation of the blank under requirement. The rigidity of the clamping set should be higher. If the clamping force is too big, it will make the work much more difficult and other unknown problems may come up. Suitable intensity of the clamping force is very important in controlling the mismatch. Fig. 6 shows the mismatch of the two blanks with the thickness of 0.7mm and 1.6mm. From the inspected results obtained by Servo-Robot, we can see that the mismatch turns smaller when the clamping force becomes bigger, but when the force is too big the mismatch turns bad. Too much clamping force leads to the deformation of the clamping beam which can affect the uniformity of the clamping force.

The deformations with clamping force can be obtained using the method which is presented in [8]. The clamping forces are to counteract the deformations of the blanks and these deformations can be assumed to result from the condition that the blanks with different edges fixed receive deformations under the uniform load q . Here the analysis will be taken based on the deformation around Y axis.

We can get the deformation of an arbitrary point on the blanks according to the flexing differential equation of thin plate [9-11]:

$$\frac{E\delta^3}{12(1-\nu^2)}\nabla^4 w = q \tag{3}$$

The symbols shown in the equation are:

w :The deformation of an arbitrary point on the blanks

q : The uniform load

E : Young's modulus of the blanks

δ : Thickness of the blanks

ν : Poisson's ratio, here $\nu = 0.3$

The deformations can be abstract as the blanks with two opposite edges fixed whose length are b deform under the uniform load q .

Based on the edge conditions, the flexivity f is:

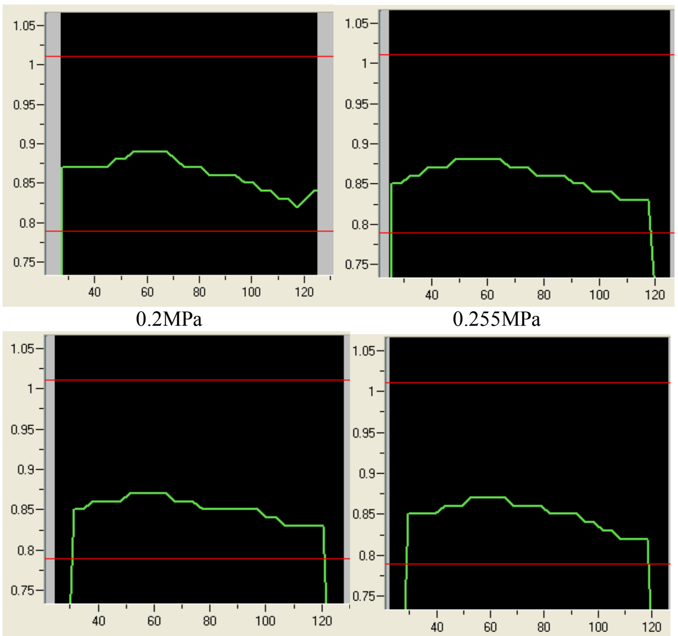
$$f = \sum_{m=1}^{\infty}[A_m ch\frac{m\pi y}{a} + B_m \frac{m\pi y}{a} sh\frac{m\pi y}{a} + C_m sh\frac{m\pi y}{a} + D_m \frac{m\pi y}{a} ch\frac{m\pi y}{a} + f_m(y)]\sin\frac{m\pi y}{a} \tag{4}$$

The coefficient of A_m , B_m , C_m and D_m can be obtained from the edge conditions, and $f_m(y)$ is the particular solution. From the actual deformations of the blanks, q can be obtained.

Then the deformations with the clamping force can be given using CATIA.

Then, mismatch produced with different clamping forces can be described as:

$$M_F = M(F) \tag{5}$$



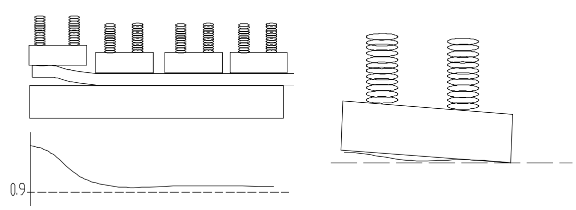
0.2MPa   0.255MPa

0.3MPa   0.4MPa

Fig. 6 Mismatch with different clamping forces

3) Uniformity of the Clamping Force

The uniformity of the clamping force which contains the uniformity between clamping plates and each plate is another important factor for mismatch. Fig. 7a shows the structure of the clamping set which clamps by springs. The different decrements of the springs lead to the non-uniform clamping forces which mean clamping plate with small decrement doesn't have a good effect on controlling mismatch. One clamping plate which contains two springs will lean if the two springs have different forces which may make mismatch (Fig 7b).



a. Clamping set   b. Clamping plate

Fig. 7 Mismatch produced by non-uniform clamping forces

4) Deformation of the Clamping Beam

The clamping beam will deform during clamping (Fig. 8). The maximum of the deformation which will make the clamping force different is about 2mm in the center of the beam.

The non-uniform forces produced by the deformation of the beam will be computed. Fig. 9a is the schematic diagram of the clamping beam. Each clamping plate contributes F_i. Before clamping, each spring has the same length:

$$l_1 = l_2 = l_i \quad (i{=}1, 2\ldots n) \tag{6}$$

when clamped, the bottom of the plates on the same level:

$$l_1' - f_1 = l_2' - f_2 = l_i' - f_i = h \quad (\text{i=1, 2…n}) \tag{7}$$

the decrement of the spring *i* is

$$\Delta x_i = l_i - l_i' \quad (\text{i=1, 2…n}) \tag{8}$$

Where $\quad l_i' = h + f_i \quad$ (i=1, 2…n) (9)

f_i is the deformation of the point *i* which can be obtained from (10).

$$EIf_i = \int[\int M_i(x)dx]dx + Cx + D \tag{10}$$

here, E is Young's modulus, I is inertia, M_i is the moment at point *i*, C and D are integral constant.

there is also:

$$F_i = k\Delta x_i \tag{11}$$

From (5)-(11), we can get the expression of F_i.

There are two ways to minimize the non-uniformity produced by the deformation of the clamping beam. One is to increase the stiffness of the beam which is an arduous task; another is to adjust the initial length of the spring to make the forces uniform (Fig. 9b). Next, the second method is described in detail.

First, calculate f_i according to (10) with the assumption that the clamping forces are uniform. When clamped, the bottoms of the plates are on the same level:

$$l_1' - f_1 = l_2' - f_2 = l_i' - f_i = h \quad (\text{i=1, 2…n}) \tag{12}$$

Because each clamping force is the same, the decrement of the spring *i* is also equal:

$$\Delta x_1 = \Delta x_2 = \Delta x_i \quad (\text{i=1, 2…n}) \tag{13}$$

The initial length of each spring can be described as (14) according to (10), (12) and (13).

$$l_i = l_i' + \Delta x_i = fi + h + \Delta x_i \tag{14}$$

The uniformity of the forces can be guaranteed by adjusting the initial length of the spring according to the result obtained above.

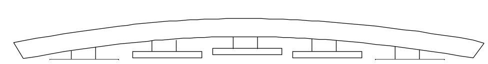
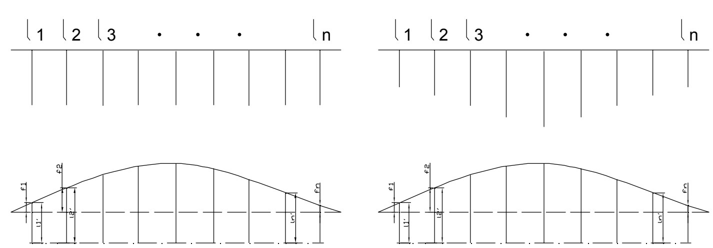


Fig. 8 Deformation when clamping



a. Before adjust   b. After adjust

Fig. 9 Schematic diagram of the clamping process

5) Flatness Error of the Based Platform

Based platform for both thin blank sheet (front based platform) and thick blank sheet (rear based platform) makes up the whole based platform. The mismatch of the two platforms caused by flatness error can also contribute to the mismatch. Measurements and experiments are taken to find how the flatness of the based platform affects the mismatch.

Micrometer gauge is used to measure the mismatch of the two based platform. The measuring principle is to measure the relative positions between the platform and the standard ruler, then deduce the mismatch of the two platforms (Fig. 10). The precision of the ruler is under 0.01mm. The ruler moves from position 1 to n with the spacing of 50mm, and the micrometer moves on the ruler and measures six points each position. The six points with 20mm the spacing can generate two lines which have two crossing points with the central line. The distance between the crossing points is the mismatch of each position. The measuring results are shown in Table I. Fig. 11 shows the mismatch curve.

An experiment is taken to find how much the mismatch of the platform affects the mismatch of the blank. The experiment is conducted on a selected section of the based platform from 200mm to 600mm. The sizes of the blanks tested are 0.7mm×400mm×500mm and 1.6mm×400mm×500mm, and the welding edge is 400mm in length. The mismatch is detected using Servo Robot (Fig. 12). From Fig. 11 and Fig. 12, we can find that the trend of the platform mismatch determine the trend of the blank to a certain extent.

Then, mismatch produced by the Flatness error of the based platform can be described as:

$$M_p = p(x) \tag{15}$$

where *p(x)* is the mismatch of the based platform.

TABLE I
MEASURING RESULTS OF THE MISMATCH OF THE BASED PLATFORM

NO.	Position (mm)	Mismatch (0.01mm)	NO.	Position (mm)	Mismatch (0.01mm)
1	0	1	19	900	-9
2	50	-4	20	950	11.5
3	100	-6	21	1000	-4.5
4	150	0	22	1050	-10
5	200	7	23	1100	-5
6	250	-2	24	1150	-7.5
7	300	-2.5	25	1200	-8
8	350	0	26	1250	-10
9	400	-0.5	27	1300	-3.5
10	450	-6	28	1350	-3.5
11	500	-2	29	1400	-1.5
12	550	-6	30	1450	-8
13	600	-4.5	31	1500	-4
14	650	-8.5	32	1550	-5
15	700	-6	33	1600	-7.5
16	750	5	34	1650	-5.5
17	800	2	35	1700	-1
18	850	1.5	36	1750	-8.5

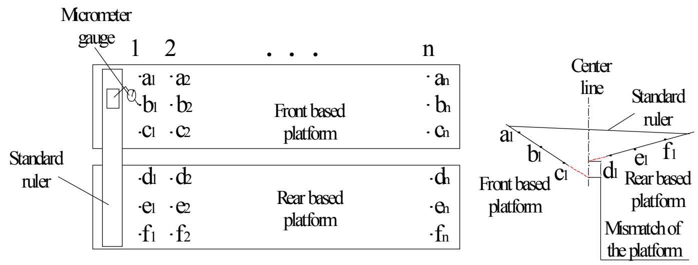


Fig. 10 Schematic diagram of the measuring principle

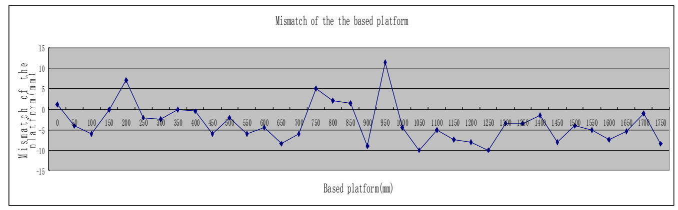


Fig. 11 Mismatch curve of the based platform

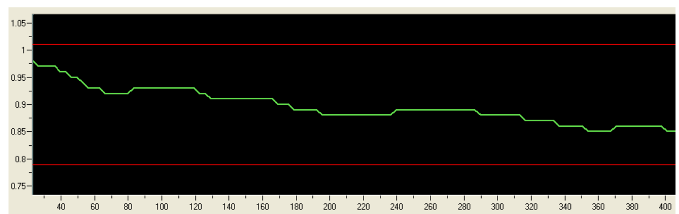


Fig. 12 Mismatch detected using Servo Robot

6) The Welding Process

Analysis of the mismatch curves before and after welding (Fig. 13) indicates that welding process also contributes to the mismatch. During welding process, the temperature distributions of the blanks are unbalanced; the materials near weld zone experience different rate of expansibility and shrinkage which makes the materials in complex 3D residual stress status and produce temporary or permanent deformation. However, little knowledge of the welding deformation has been obtained [12]. Although, numeral modelling method for welding deformation have been provided with the development of computer technique, there are still several difficulties in the modelling precision for little knowledge of the materials in high temperature and complex computation. This paper introduces an empirical magnification function to describe the mismatch produced by welding process.

$$M_{after} = k(h_1, h_2) M_{before} \tag{16}$$

where M_{after} is the mismatch after welding, M_{before} is the mismatch before welding and $k(h_1,h_2)$ is the empirical magnification function.

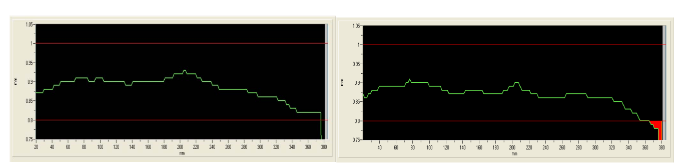


Fig. 13 Mismatch before and after welding

IV. MATHEMATICAL MODEL OF THE MISMATCH

Mathematical model of the mismatch can be given as (17) according to the analysis in part III.

$$M = M_{bd} + M_F + M_{equ} + M_{cbd} + M_p + M_w \tag{17}$$

where M is the total mismatch, M_{bd} the mismatch produced by deformation of the blanks, M_F the mismatch produced by the clamping force, M_{equ} the mismatch produced by the uniformity of the clamping force, M_{cbd} the mismatch produced by the deformation of the clamping beam, M_p the mismatch produced by flatness of the based platform, M_w the mismatch produced during welding process. M_{equ} can merge into M_F, then (17) can be simplified as the following:

$$M = M_{bd} + M_F + M_{cbd} + M_p + M_w \tag{18}$$

V. EXPERIMENT AND SIMULATION

Experiment is done on the Automatic Tailored Blank Laser Welding machine in displaced in part II. The blanks to be test are 0.7mm×400mm×500mm and 1.6mm×400mm×500mm, and the welding edge is 400mm in length. The measuring equipment is Servo Robot.

A. Deformation of Blanks

The deformation curvatures of the 0.7mm blank round X and Y axis is 1×10^4mm and 1.3×10^4mm. And the deformation curvatures of the 1.6mm blank round X and Y axis is 1.5×10^4mm and 2.0×10^4mm.

B. Clamping Force

The clamping force is 12000N/m, and it is 10mm distance from the welding edge.

C. Mismatch of the Based Platform

The experiment is conducted on a selected section of the based platform from 200mm to 600mm. Table I gives the numerical value of the mismatch of the based platform.

D. Welding Process

The welding parameters are as follows: laser power: 4kw, welding speed: 6.8m/s, defocus: 0.6mm, offset: 0.08mm.

E. Simulation and Analysis

The mismatch of the blanks can be obtained according to (18).

First, the deformations of the blanks around X axis after clamped are as followings according to (1)

$$f_{bd1} = f_{bdx1} = R_{x1} - \sqrt{R_{x1}{}^2 - l^2} \;,$$

$$f_{bd2} = f_{bdx2} = R_{x2} - \sqrt{R_{x2}{}^2 - l^2}$$

The deformation curve is shown in Fig. 14.

The clamping forces are considered to be uniform after the initial lengths of the springs adjusted. Fig. 15 gives the deformation of the blanks around Y axis after clamped based on the finite element analysis.

Fig. 16 shows the mismatch of the selected section of the based platform from 200mm to 600mm.

Then, the specific expression of the empirical magnification function is described as (19) under the welding parameters mentioned above.

$$k(h_1, h_2) = 4/3 \tag{19}$$

Finally, the total mismatch which is shown in Fig. 17 is the sum of the mismatch obtained above. Fig. 18 is the mismatch detected by Servo Robot which is a laser vision system for weld inspection. The comparison between Fig. 17 and Fig. 18 indicates that the mismatch gotten by the mathematical model has a good agreement with the result detected by Servo Robot.

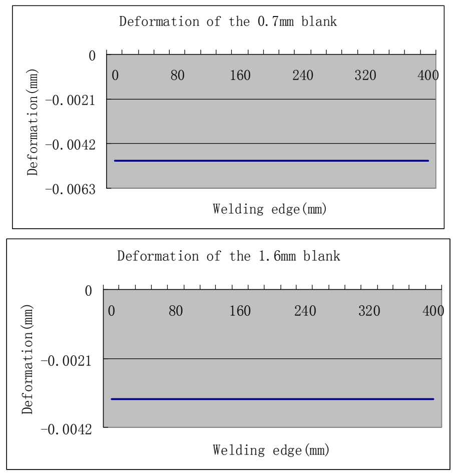


Fig. 14 Deformations of the blanks around X axis after clamped

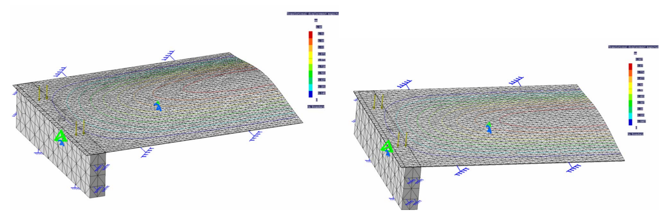


Fig. 15 Finite element analysis result

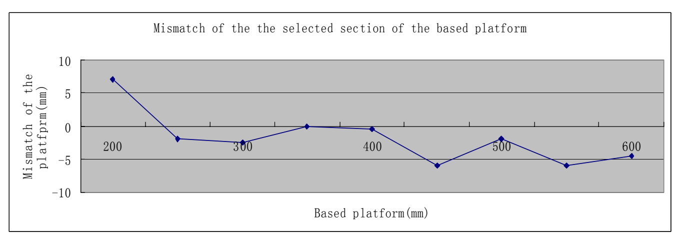


Fig. 16 Mismatch of the selected section of the based platform

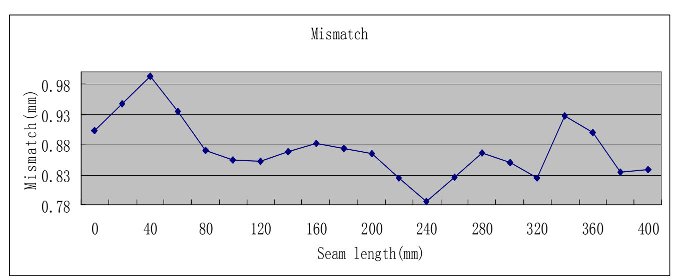


Fig. 17 Mismatch Obtained by simulation

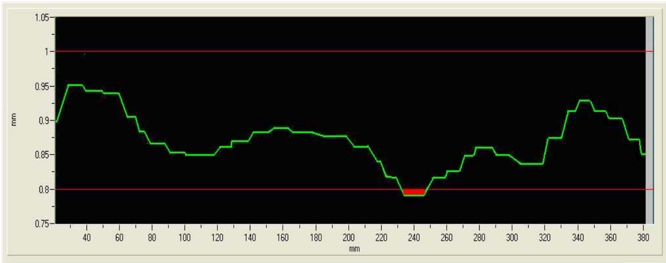


Fig. 18 Mismatch detected by Servo Robot

VI. CONCLUSION

The research on mismatch of Tailored Blank Laser Welding system is conducted in this paper. Analysis and mathematical modeling method for the mismatch are briefly described. Experiment is carried out to examine the precision of the model.

Based on the analyses and experiments present in this paper, the following conclusions may be made:

1) Analyses and experiments suggest that there are numerous originals affect mismatch in Tailored Blank Laser Welding.

2) The specific expression of empirical magnification function is obtained based on a large number of experiments.

3) The comparisons between experiment and simulation results indicate that mathematical model for mismatch has a good effect in predicting mismatch.

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