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Control Parameters Analysis Of Ultrasonic Plastic Welding Machine By Using Neural Network

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Abstract: *This research aims to employ the technique of neural network (NN) into the analysis of control parameters for the ultrasonic plastic welding machine. An intelligent mechanism for the precise control of ultrasonic plastic welding process is expected to be developed. The NN technique is used to find the importance of individual control parameter of welding machine. The influence rate (IR) of each control parameter is able to be obtained by using a novel calculation method. Thus, based on such an intelligent control mechanism developed, the optimal control for the best welding process could be easily executed.*

Keywords: *neural network, control parameters, precise control, ultrasonic welding machine*

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I. INTRODUCTION

It is known that the protection of electronic product has become more and more important, especially for those products must be protected and forbidden to open. For instance, many electronic products such as the battery cases of computer, cell phone, adaptor and the connector of USB transmission line, all have such necessity. In general, in order to avoid the defective condition caused by man-made or dust, the electronic circuit and component will be covered and protected by the plastic case. The plastic case could not only protect the product and make its function work well, but also let the user can not open the case easily. Fig. 1 shows some pictures of electronic products with covered plastic cases.

(a) USB Connector **(b) Electric Plug**

Figure 1: The electronic products with covered

Generally, the entire cover case of electronic product is composed of by two casings, i.e. upper casing and lower casing. The whole casing process is usually made by ultrasonic plastic welding machine which is a joining process of thermoplastic through the use of heat generated from high-frequency mechanical motion. The heat at plastic components' connected surfaces could melt the plastic material and then form a molecular bond between the connection parts. Fig. 2 shows the principle of ultrasonic plastic welding process. In fact, in the real ultrasonic plastic welding process, 1%~3% production defective rate is reasonably accepted by the technician. Because, too many possible influence factors such as welding energy, pressure, curing time, descending speed, amplitude, delay time, etc., could affect the quality of welding product. Thus, how to find the real impact on the welding quality by these factors is an important work for the welding technician. For a large amount of products, even 1% defective rate could result in a big loss to the company. Sometimes, the loss could reach to ten millions or a billion dollars per year.

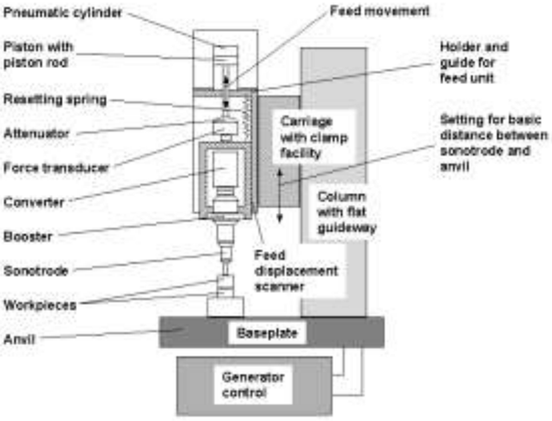


Figure 2: The principle of ultrasonic plastic welding process. (https://techcenter.lanxess.com)

In past two decades, how to improve the welding quality of ultrasonic welding machine had been studied and reported. The literatures [1-2] reported the welding qualities for different products based on different materials, [3-5] focused on the impacts caused by the different parameters during the welding process. [6-7] investigated the problems of welding controller. The reliability of the welding function for the ultrasonic energy converter is discussed in [8]. The articles [9-10] did the research about the vibration pressures, [11-15] discussed the characteristic analysis of welding machine for different plastics in different vibration frequency operations. The impact of temperature changes are presented in [16-18]. In order to find the influences to the welding quality due to the operational parameters of ultrasonic welding machine, the method of finite element analysis has also been studied in this area [19-22]. The articles [23-27] show the works to analyze the relationships and effects by the amplitude, pressure, welding time, curing time and temperature using statistical methods.

In recent years, due to the fast development of artificial intelligent (AI) technology, such as neural network (NN), fuzzy theory, genetic algorithm, etc., have been widely used in the studies of system modeling and signal processing. In which, NN is the most popular method used in the signal processing since its powerful learning capability. In this study, we aims to develop an AI welding mechanism for the precision control of ultrasonic welding machine. The whole research will focus on the analysis among the possible welding influencing factors, plastic materials and welding process. An optimal operation process based on AI technique is expected to be developed for helping the technician to do the best welding work.

II. NEURAL NETWORK

In this research, NN technique is the main tool used for constructing AI mechanism. The nonlinear relationship between input and output pairs is expected to be obtained through the efficient learning of NN. The NN structure commonly known as multi-layered feed-forward network is used in our research. The supervised NN with error back-propagation (BP) learning algorithm is taken for NN's training [28-30]. In order to find the individual importance of each input variable to the output while NN is well-trained, a novel method will be used for calculating the influence rate (IR) [31]. Here, we use a simple three-layered NN model with size 2-3-1 to describe IR calculation method created. Its structure is shown in Fig. 3.

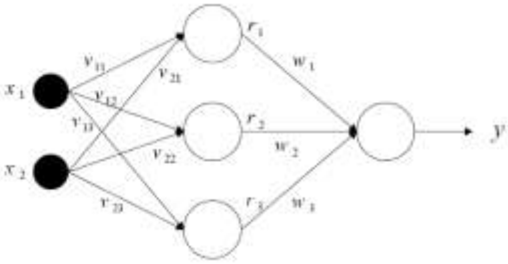


Figure 3: The structure of 2-3-1 NN model.

In Fig. 3, due to the sigmoid function is an increasing function, the following relationships among the inputs (x_1, x_2), the outputs of hidden nodes (r_1, r_2, r_3) and the output node (*y*) can be expressed as

$$r_j \propto \sum v_{ij} x_i + \theta_j \qquad (1)$$

$$y \propto \sum w_j r_i + \theta_0 \qquad (2)$$

$$y \propto \sum w_j (\sum v_{ij} x_i + \theta_j) + \theta_0 \qquad (3)$$

v_{ij} is the strength of connection between hidden node *j* and input node *i*; w_j is the strength of connection between hidden node *j* and output node. θ_0 and θ_j are bias terms. The influence rate (IR) and the percentage influence rate (PIR) of input x_i to the output *y* then can be defined by

$$\mathrm{IR}_i = \sum_{k=1}^{\mathrm{NT}} \left| \sum_j w_j(k) v_{ij}(k) x_i(k) \right| \qquad (4)$$

$$\mathrm{PIR}_i = \mathrm{IR}_i \Big/ \sum_{i=1}^{\mathrm{m}} \mathrm{IR}_i \qquad (5)$$

where, NT is the total number of input x_i and m is the categories of input variables.

III. EXPERIMENTS

As previous description, this research aims to analyse the control parameters of ultrasonic welding machine by using NN model. The adapter shown in Fig. 4 is used as an example for this research. Fig. 4(a) shows the image of power adaptor which was produced by ultrasonic welding machine. Fig. 4(b) presents four test points A, B, C and D, which are used for testing whether the adaptor is a qualified product or not.

(a) **(b)**

Figure 4: The power

Table I shows an example of testing points, A, B, C, D, with different welding parameters. In the table, Gap means the joint spacing between upper shell and lower case. Step stands the distance of upper shell subsided in the lower case. For a good and qualified product, the measurements of Gap and Step must be within the following ranges.

Gap: 0.0 mm to 0.2 mm, Step: -0.10mm ~ 0.05mm.

Any product's Gap or Step measurement is beyond the measurement scope, it will be treated as defective and must be re-produced.

In our research, 85 data sets were used for study. In which, 60 data sets were used for NN's training and 25 data sets were used for testing. Eight independent NNs were used, each one is responsible for the individual Gap and Step points. The size of all NN models is 6-8-1. Table II shows the percentage influence rate (PIR) of each influence variable on the training and testing results of A, B, C, D Gaps by four NNs.

Based on Table II shown, the importance of each welding control parameter to four Gaps can be summarized as follows.

For Gap A; Amplitude > Descending speed > Curing time > Pressure > Energy > Delay time.
For Gap B; Descending speed > Amplitude > Pressure > Curing time > Energy > Delay time.
For Gap C; Descending speed > Amplitude > Pressure > Curing time > Energy > Delay time.
For Gap D; Descending speed > Amplitude > Energy > Curing time > Pressure > Delay time.

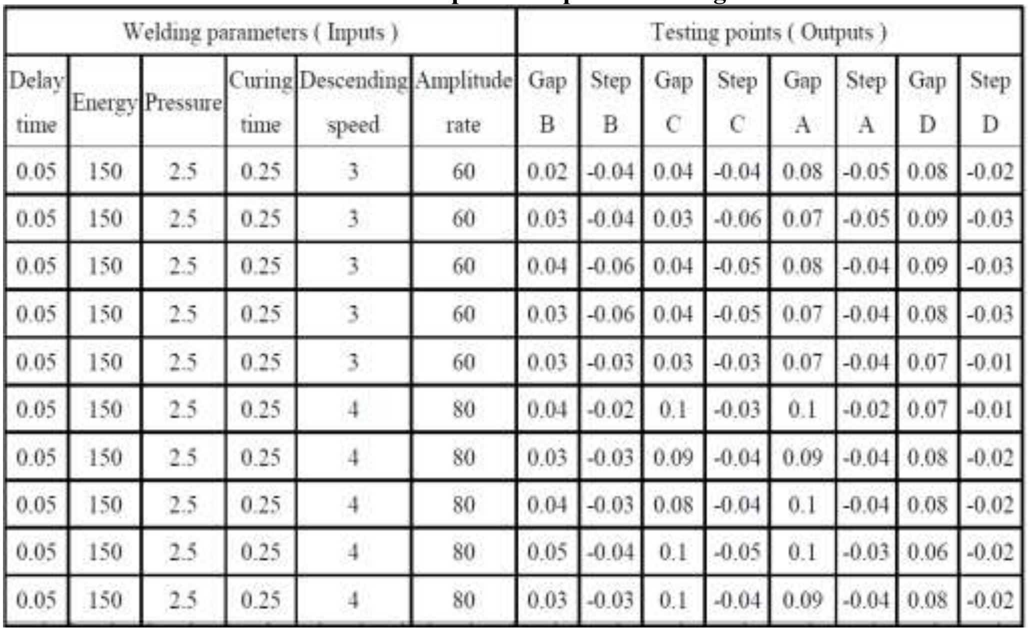
Taking a comprehensive summary, descending speed, amplitude and pressure can be concluded three most important influencing factors for Gaps.

Similarly, the studies for four Steps by NN models were also analyzed. Table III lists the PIR values for the training and testing results of A, B, C, D Steps by four NNs. In Table III, the importance of each welding control parameter to four Steps can also be summarized as follows.

For Step A; Descending speed > Pressure > Amplitude >Curing time > Delay time > Energy.
For Step B; Descending speed > Pressure > Amplitude > Delay time > Energy > Curing time.
For Step C; Descending speed > Pressure > Energy > Curing time > Amplitude > Delay time.
For Step D; Descending speed > Amplitude > Pressure > Energy > Delay time > Curing time.

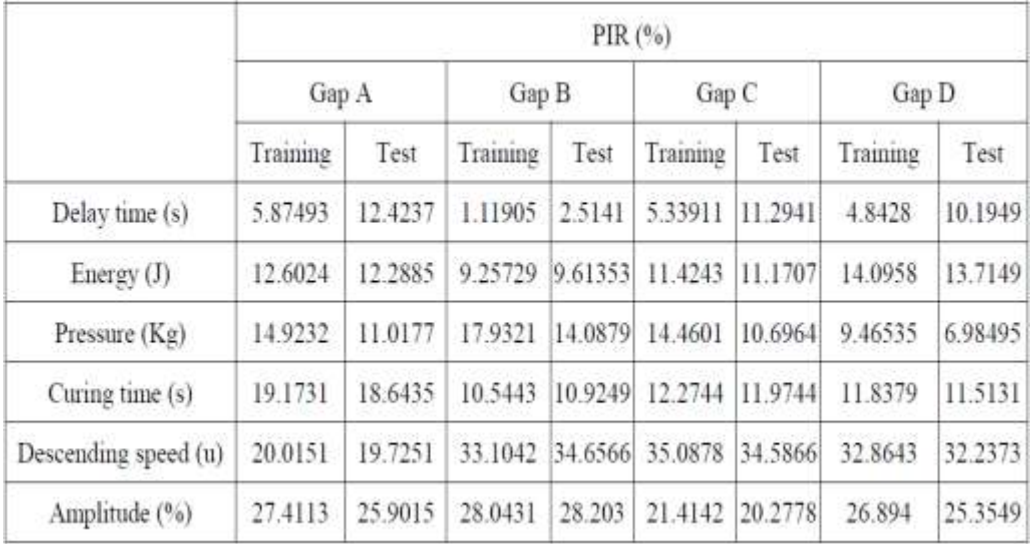
Again, taking a summary, we conclude that descending speed, pressure and amplitude are three most important influencing factors for Steps either.

Table I: The example of adaptor's welding data.



Welding parameters (Inputs)						Testing points (Outputs)							
Delay time	Energy	Pressure	Curing time	Descending speed	Amplitude rate	Gap B	Step B	Gap C	Step C	Gap A	Step A	Gap D	Step D
0.05	150	2.5	0.25	3	60	0.02	-0.04	0.04	-0.04	0.08	-0.05	0.08	-0.02
0.05	150	2.5	0.25	3	60	0.03	-0.04	0.03	-0.06	0.07	-0.05	0.09	-0.03
0.05	150	2.5	0.25	3	60	0.04	-0.06	0.04	-0.05	0.08	-0.04	0.09	-0.03
0.05	150	2.5	0.25	3	60	0.03	-0.06	0.04	-0.05	0.07	-0.04	0.08	-0.03
0.05	150	2.5	0.25	3	60	0.03	-0.03	0.03	-0.03	0.07	-0.04	0.07	-0.01
0.05	150	2.5	0.25	4	80	0.04	-0.02	0.1	-0.03	0.1	-0.02	0.07	-0.01
0.05	150	2.5	0.25	4	80	0.03	-0.03	0.09	-0.04	0.09	-0.04	0.08	-0.02
0.05	150	2.5	0.25	4	80	0.04	-0.03	0.08	-0.04	0.1	-0.04	0.08	-0.02
0.05	150	2.5	0.25	4	80	0.05	-0.04	0.1	-0.05	0.1	-0.03	0.06	-0.02
0.05	150	2.5	0.25	4	80	0.03	-0.03	0.1	-0.04	0.09	-0.04	0.08	-0.02

Table II: The PIR values of each influence variable for Gaps.



	PIR (%)							
	Gap A		Gap B		Gap C		Gap D	
	Training	Test	Training	Test	Training	Test	Training	Test
Delay time (s)	5.87493	12.4237	1.11905	2.5141	5.33911	11.2941	4.8428	10.1949
Energy (J)	12.6024	12.2885	9.25729	9.61353	11.4243	11.1707	14.0958	13.7149
Pressure (Kg)	14.9232	11.0177	17.9321	14.0879	14.4601	10.6964	9.46535	6.98495
Curing time (s)	19.1731	18.6435	10.5443	10.9249	12.2744	11.9744	11.8379	11.5131
Descending speed (u)	20.0151	19.7251	33.1042	34.6566	35.0878	34.5866	32.8643	32.2373
Amplitude (%)	27.4113	25.9015	28.0431	28.203	21.4142	20.2778	26.894	25.3549

Table III: The PIR values of each influence variable for Steps.

	PIR (%)							
	Step A		Step B		Step C		Step D	
	Training	Test	Training	Test	Training	Test	Training	Test
Delay time (s)	9.68826	19.8517	11.0315	22.3111	9.405	19.3636	8.54739	17.6548
Energy (J)	8.43694	7.96729	9.3993	8.78709	18.1936	17.3411	17.7905	16.9989
Pressure (Kg)	22.3079	16.0279	22.8505	16.1662	24.2641	17.5676	19.7507	14.2628
Curing time (s)	11.5366	10.9984	9.28453	8.66175	12.478	11.8792	8.83123	8.4303
Descending speed (u)	28.0533	26.723	31.1784	29.3696	24.8213	23.805	24.5722	23.7079
Amplitude (%)	19.977	18.4317	16.2558	14.7043	10.838	10.0436	20.508	18.9452

From above studies of Gaps and Steps, it is clearly found that descending speed, amplitude and pressure are three most important control parameters in the ultrasonic plastic welding process. In part of Gaps, amplitude is more important than pressure. However, in part of Steps, the condition is reversed, pressure is more important than amplitude.

In order to see the actual influencing condition of three important factors to Gaps and Steps, respectively, the experiments of changes of Gaps and Steps versus individual parameter were performed. The results are presented in Fig. 5 to Fig. 10. From the figures shown, the effect of descending speed to Gaps and Steps is indeed greater than other two influencing factors. In addition, the effect of amplitude to Gaps is greater than pressure and the effect of pressure to Steps is greater than amplitude.

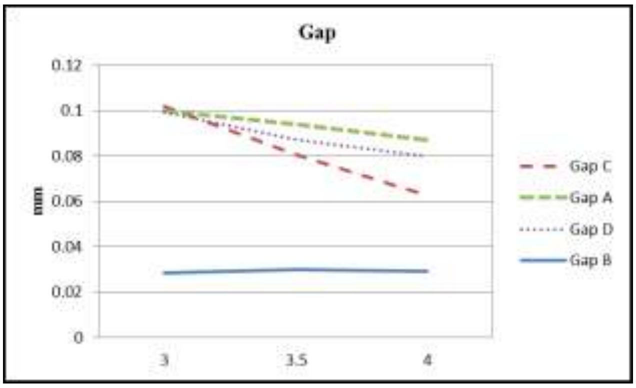


Figure 5: Descending speed vs. Gaps.

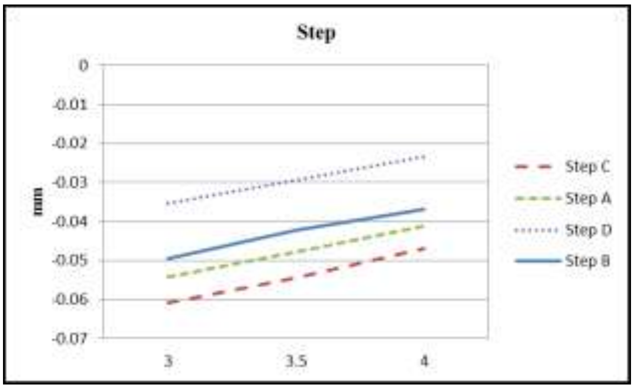


Figure 6: Descending speed vs. Steps.

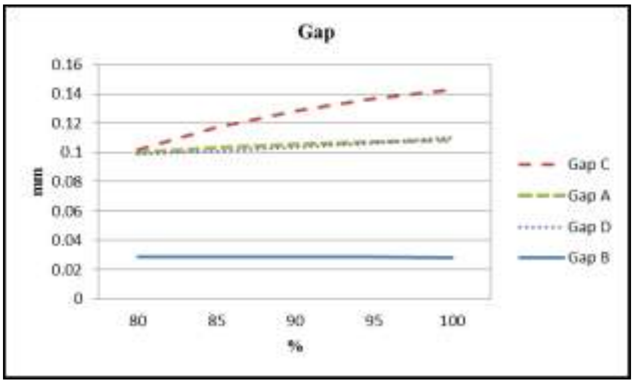


Figure 7: Amplitude vs. Gaps

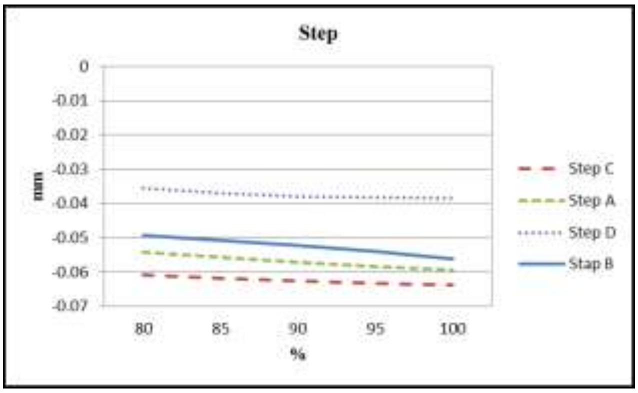


Figure 8: Amplitude vs. Steps.

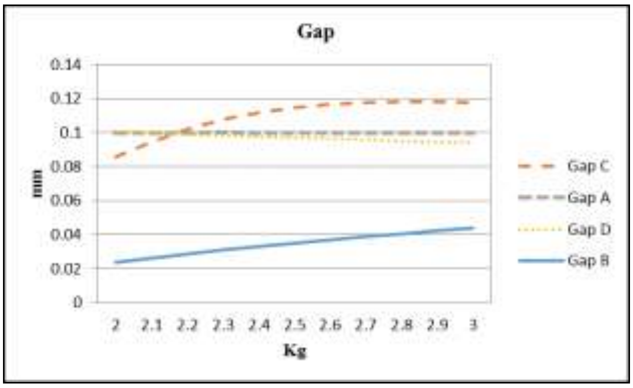


Figure 9. Pressure vs. Gaps.

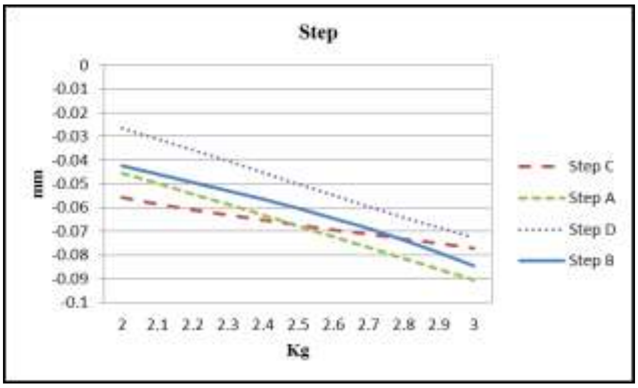


Figure 10: Pressure vs. Steps

IV. CONCLUSION

In this research, the intelligent precise control mechanism for ultrasonic plastic welding machine is studied. An AI analyzer of control parameters for the ultrasonic plastic welding process is developed. As we know, for most of ultrasonic plastic welding works, the control process is usually based on the experience of senior technician. Sometimes, it can be called the expert system. Thus, the parameter's adjustment of welding machine must rely on the actual operational condition and trial-and-error is still unavoidable. Thus, in our studies, the artificial NN model was used to analyze the relationships among the welding parameters and the product outputs (Gaps, Steps). It can be found that the descending speed, amplitude and pressure are three most important influencing control parameters in the real ultrasonic plastic welding process. Such an analysis has been confirmed by the online operational technician and recognized that our research results are correct. Therefore, we conclude that an AI mechanism for the optimal control of ultrasonic plastic welding process is possibly designed and developed. Such a smart mechanism could help the technician with no experience to do the best welding work easily. Based on this AI system, not only the cost of company could be reduced, but also the defective rate of product could be decreased.

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