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Article

Design the Separation Method and Holder for Plastic Lenses

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Abstract: Plastic lenses are very fragile and scratch easily. Therefore, to remove the plastic lens from the door without causing any damage, a precise base bracket is required. This article describes a method for separating plastic lenses using a 15 KHz ultrasonic horn. In this case, EDM and servo motors are used to make micro on the base holder by adjusting the gap voltage, pulse on time, pulse off-time, and outlet water pressure. To check longitudinal vibration at 15 KHz frequencies for ultrasonic horns, perform harmonic analysis by providing 15KHz frequency as the input value. The experimental results demonstrated that the average error of machining micro-holes is 0.01025 mm by EDM. The ultrasonic horn is designed to fit with 15 KHz, after tuning the ultrasonic vibration, the total machining time is 1.25 seconds, and all the plastic lenses on the workpiece gate can break within one cycle. The quality accuracy of the plastic lens is 90.83%.

Keywords: EDM, Ultrasonic horn, Plastic lenses, Micro-hole array

1. Introduction

In recent years, the plastic lens has become well-known to increase the light collection efficiency of CCD and CMOS sensors. A plastic lens is also used in digital cameras with excellent optical quality. One of the advantages of this lens is that it is very thin and light. Before lenses are installed, inspection is very necessary to check the lens's condition such as dust particles and any other damages. Lenses are very sensitive and easily scratched when using a clamping device to detach lenses. Therefore, using the vacuum to provide suction to pick up lenses to avoid any damage and scratches. Abbas et al. [1] studied that a precision component like a microlens, how to place and assemble the device and achieve the same function without damaging its surface is very important. Gao and Liu [2] proposed a micro-EDM method for machining deep micro-holes in difficult-to-machine materials. Li et al. [3] mentioned that electrical discharge machining is non-traditional machining, especially microhole array machining, which has the advantages of large aspect ratio and non-contact machining. Palanisamy et al. [4] proposed an electrical discharge machining method for aluminum, which significantly improves the surface roughness and processing speed of aluminum. Lim et al. [5] used an XY-Table to control an electric discharge machine. Microhole machining can use EDM to machine parts and use position control to control the X and Y directions. Python is used with a pulse generator to control the servo motors. In this study, combine servo motor system controller with Electrical Discharge Machining (EDM) to be designed micro-holes. Design ultrasonic horn and use harmonic analysis by providing 15KHz frequency as the input value.

2. Design of Base Holder

The design of the base holder is shown in Fig. 1. There are 8 groups of pitch circles formed into a symmetrical square. The distance from the center of the pitch circle to the center of the holder is 30mm in the X and Y directions, and the distance from the center of the adjacent circle in the X and Y directions is 20mm. The area of the base is 100*100mm, and the thickness of the base is 10mm. Since EDM is used to make microporous arrays, and EDM is only suitable for conductors, the material choice is metal conductors. Aluminum is light, flexible, easy to machine, and has an oxidation-resistant anodized finish, making it ideal for this application and design.

Circular array parameters are pitch circle diameter (D = 3.3mm). The array number is 8. The diameters of the 6 pitch circles are the same as 3.3mm, and the angles from the center line (θ). The center position of every pitch circle has a tolerance of ±0.1 mm. Each piece of pitch circle has a diameter of 3.3mm and a tolerance of ±0.05 mm. Each group of pitch circle array has 6 micro-holes with 0.4 mm diameter. Thus, there are a total of 48 micropores on 8 pitch circle groups, as shown in Fig. 2 below.

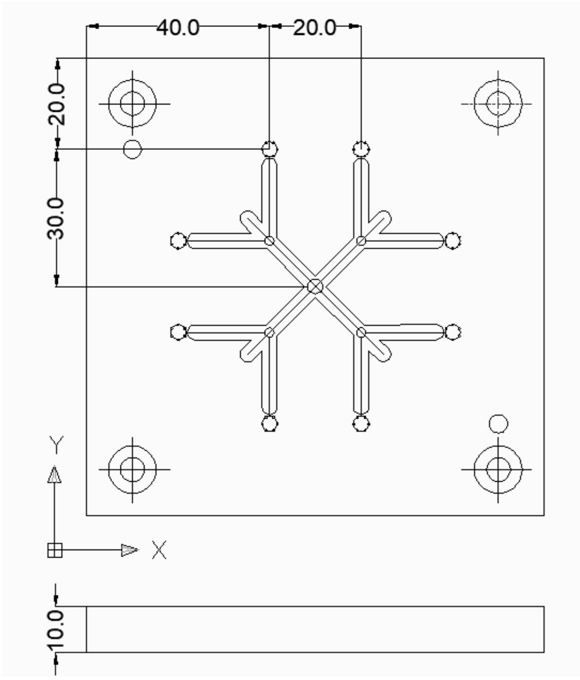

Fig. 1. Layout of microlenses.

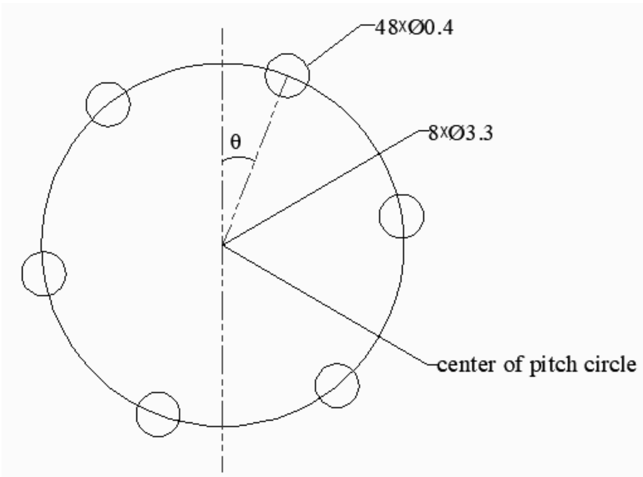

Fig. 2. Circle row array and Parameters.

With help of the above parameters, the position coordinates of all circles can be calculated as unknown parameters in Eqs. (1) and (2).

$$x_t = x_0 + 1.65 * (\sin(60 * t + \theta)) \tag{1}$$

$$y_t = y_0 + 1.65 * (\cos(60 * t + \theta)) \tag{2}$$

where t is the number of circular array holes, from 1 to 6. θ is the angle of rotation.

Python language is an object-oriented programming language. The advantage of Python is that is easy to understand and easy to compile. Therefore, Python language is used as the programming language of the upper controller of the servo control system. The architecture diagram of the servo control system is shown in Fig. 3. The host controller is connected to the network communication pulse generator and lens through Ethernet. Lenses in Network Pulser communicate via network sockets. After that, the network communication pulse generator communicates with the servo drive via the pulse wave and the C N1 of the digital input servo drive. The servo driver controls the servo motor through UVW. There is an encoder at the rear end of the servo motor, which is connected to CN3 of the servo drive to form a semi-closed-loop control. The servo motor is connected to the X and Y axes through the coupling to control the mechanism. The servo motor encoder used is 22 bits. There set the electronic gear ratio of the servo controller, and the motor makes one revolution every 5000 pulses. The screw lead used here is 5 mm $\frac{5000}{4{,}194{,}304}$. Therefore, the resolution of the servo control system is 0.001 mm/Pulse or 1 μm/Pulse.

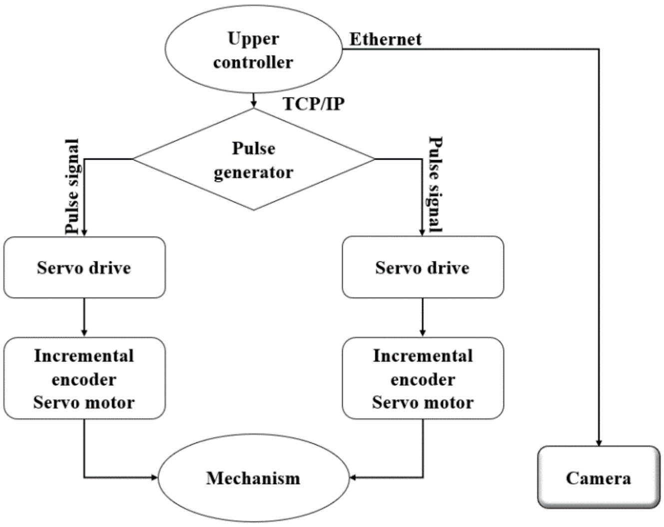

Fig. 3. Schematic diagram of servo control system.

The architecture of the servo control system is shown in Fig. 4. From Fig. 4, classes are used to define each axis. The objects are used to describe the parameters and functions used to control the axes. Objects include axis number, whether the motor is excited or not, origin, starting speed, travel speed, acceleration time, changing electrodes, camera position (displacement), and direct movement. The action is to update the objects in the respective axis classes via the buttons. Then, there send information to the network communication pulse generator through the network socket, which read and displays the feedback information.

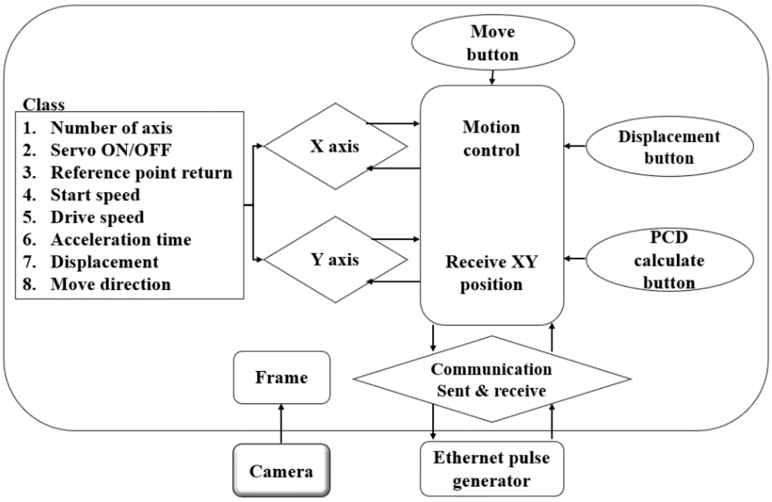

Fig. 4. Architecture diagram.

Table 1 shows processing parameters. Liquid dielectric is pure water, the material of the electrode is brass, the workpiece materials are aluminum, the electrode diameter is 0.3 mm, the gap voltage is DC 70 V, the pulse on-time is 32 μs, pulse off-time is 9 μs, and the pressure of water is 85 kg/cm^2.

Table 1. The EDM machining parameters.

1	Liquid dielectric	Pure water
2	Material of electrode	Brass
3	Workpiece material	Aluminum
4	Electrode diameter	Ø0.3 mm
5	Gap voltage	D.C. 70 V
6	Pulse on-time	32 µs
7	Pulse off-time	9 µs
8	Pressure of water	85 (kg/cm^2)

P1 starts from the top right, the diameter of P1 is 3.3 mm and the XY position of P1 is (40 mm, and 80 mm). P2 is in the upper left with the same diameter as P1 and the XY position of P2 is (60 mm, and 80 mm). P3 and P4 are respectively symmetrical to points P1 and P2 through the center of symmetry, and the XY positions of P3 and P4 are (40 mm, 20 mm), (60 mm, and 20 mm) respectively. P5 and P6 are on the left, and the XY positions are (20 mm, and 40 mm), (20 mm, and 60 mm), respectively. P7 and P8 are symmetrical to P5, P6, and the coordinates are (80mm, and 40mm), (80mm, and 60mm) respectively. P3, P4, P5, P6, P7, and P8 have the same diameter of 3.3 mm. The average error can be calculated by (3), (4), and (5). By using the desired negative current and getting the average. From Table 2, the average error of the X position is about 6 µm, the average error of the Y position is about 5.875 µm, and the average error of diameter is about 10.25 µm.

$$E_d = \sum_{i=1}^{8} |(p_d - p_m)_i| /8 \tag{3}$$

$$E_x = \sum_{i=1}^{8} |(x_d - x_m)_i| /8 \tag{4}$$

$$E_y = \sum_{i=1}^{8} |(y_d - y_m)_i| /8 \tag{5}$$

where E_d is the mean error of pitch circle diameter. p_d is the desired diameter of the pitch circle. p_m is the measured diameter. E_x is the mean error of the X-coordinate. x_d is the desired position, X. x_m is the measured position, X. E_y is the mean error of the Y-coordinate, y_d is the desired position Y, and y_m is the measured position Y.

Table 2. Measurement results.

No.	p_d (mm)	x_d (mm)	y_d (mm)	p_m (mm)	x_m (mm)	y_m (mm)
1	3.3	40	80	3.318	39.986	79.999
2	3.3	60	80	3.317	59.986	80.01
3	3.3	40	20	3.313	40.002	20.983
4	3.3	60	20	3.31	59.987	19.996
5	3.3	20	40	3.29	19.999	39.986
6	3.3	20	60	3.309	20	60.002
7	3.3	80	40	3.3	80	79.998
8	3.3	80	60	3.295	79.996	80.014
Avg Error:				0.01025	0.006	0.005875

3. Design of Ultrasonic Horn

In this study, a circular catenoid horn shape is selected, because a circular catenoid horn shape helps amplify the horn amplitude and reduce the stresses. Fig. 5 shows a half-section of the designed ultrasonic horn, which is based on a previous reference design by Cornel et al. [6] The length of the horn is 155 mm, which is suitable for two frequencies of 15 KHz and 20 KHz, and 15 KHz is selected. Change the other parameters until the ultrasound is generated longitudinally at a frequency of 15 KHz within the tolerance range. To fit with the base holder's area of 100 mm × 100 mm, the output surface radius is chosen 65 mm, which means the diameter is 120 mm. It can cover the base holder surface. Afterward, the output face diameter is smaller than the input face diameter, and analytical experience is applied. The input surface radius is selected as 75 mm, that is, the diameter is 150 mm. The input length is 80 mm, the radius is 62.71, and the output length is 18 mm. At this size, the ultrasonic horn produces longitudinal motion at a frequency of 15 KHz. The design radius is 62.71, increasing the radius produces a smoother curve. Dipin Kumarl et al. [7] suggested reducing the stress concentration on the ultrasonic horn by adjusting the radius between the input and output lengths. All of the dimensions perform analysis so many times to achieve optimum results.

Aluminium Alloy to be material of ultrasonic horn, where its Poisson's ratio is 0.33, its young's modulus is 71 GPA, and its density is 2770 kg/m^3. The wavelength is about $\lambda = \frac{1}{15000}\sqrt{\frac{71000000000}{2770}} = 0.3375$ m. Thus, half of the wavelength is 168.75 mm. Nearly 155 mm, there is using longitudinal vibration harmonic analysis to simulate 15 KHz vibration motion and design ultrasonic horn. The design of an ultrasonic horn involves multiple steps to create an optimal design. Fig. 6 shows step by step design of the ultrasonic horn. The first step is vibrational frequency selection, 15 KHz is selected. In the second step, select horn material, based on properties and fatigue strength, Aluminium material is selected. The third step is the design of the ultrasonic horn, based on citations of the author, the length of the horn is 155 mm. Other parameters are changed until ultrasonic produces longitudinal vibration motion and low stress at 15 KHz. The fourth step is the manufacture of an ultrasonic horn.

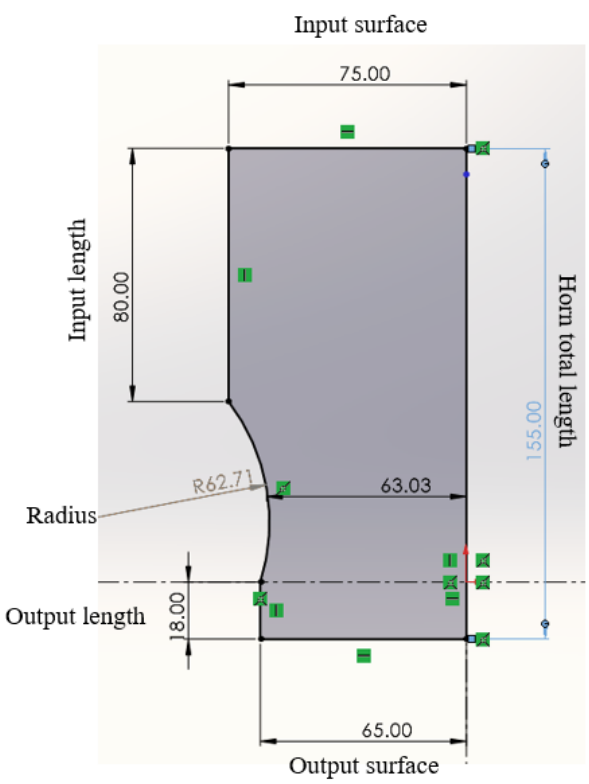

Fig. 5. Design ultrasonic horn half-section view.

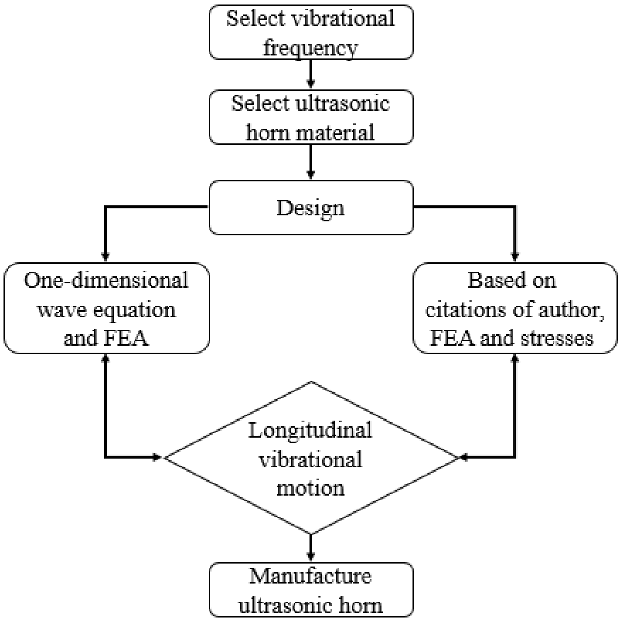

Fig. 6. Architecture diagram of ultrasonic horn design.

To reduce the stress of the ultrasonic horn in the finite element analysis, the diameter and radius were increased and decreased by using the hit test method. Vary the parameters according to the area in the ultrasonic horn where the stress effect is greatest. In this design, by keeping the length of the horn constant, other parameters are varied. The ultrasonic horn is redesigned through the impact test method until it produces a longitudinal vibration movement with a frequency of 15 KHz.

Fig. 7 shows the longitudinal vibrational motion of the designed ultrasonic horn at 15 KHz frequency in harmonic analysis. Thus, the harmonic analysis is performed by providing a frequency of 15KHz as input and checking the vibration motion at 15 KHz frequency. As shown in Fig. 7 below, two conditions in the harmonic analysis are met. At a frequency of 15 KHz, a longitudinal vibration motion is generated, as shown in Fig. 7.

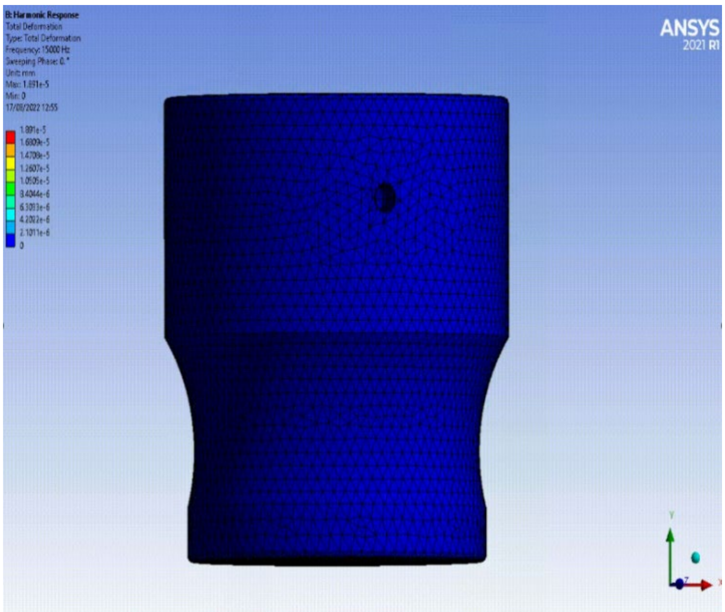

Fig. 7. Design ultrasonic horn harmonic analysis at 15 KHz.

Fig. 8 shows the 15 KHz ultrasonic horn fabricated after design and analysis. The need to be able to generate vibrations along axes of forward and backward motion at low stress, directional strain, and total strain is met.

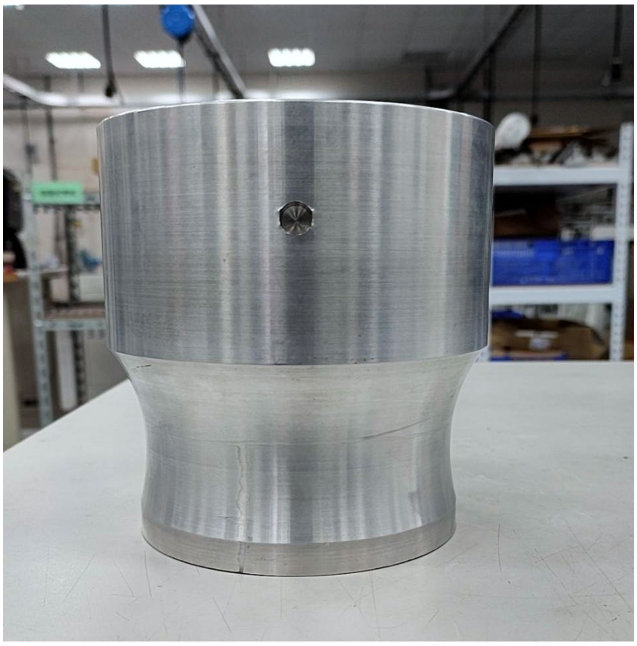

Fig. 8. Design of Ultrasonic Horn.

4. Experimental Results

In this experimental result, an experiment in real-time to detach the plastic lens. After installing the designed ultrasonic horn on the ultrasonic machine. By adjusting the vibration time and rest time, the ultrasonic machine settings start tuning. Because, if not adjusted, the plastic lens surface can be damaged by excessive vibration. Therefore, there is important to make adjustments to avoid scratches and cracks on the surface and edges of the plastic lenses. The machining tuning parameter of the SJ-26a ultrasonic horn is set to rest on time for 0.50 seconds, vibration time for 0.45 seconds, and a total time of 1.45 seconds. The tuning parameters of the design ultrasonic horn are shown in table 3. For our design of ultrasonic horn, when the ultrasonic start machining, the ultrasonic horn attaches the molded plastic lens base holder and rest on the base holder for 0.48 seconds (T_b). Then, the ultrasonic machine is vibrated for 0.29 seconds (T_v). Finally, rest on the base holder for 0.48 seconds (T_a) and return to the original position. The total machining time is 1.25 seconds (T_t) for machining operations performed in a single pass. Our ultrasonic horn design (1.25 seconds total time) is faster than the SJ-26a ultrasonic horn (1.45 seconds total time).

Table 3. Machining tuning parameters of the ultrasonic horn.

T_b (seconds)	T_v (seconds)	T_a (seconds)	T_t (seconds)
0.48	0.29	0.48	1.25

The damage to the plastic lens is shown in Fig.9. Because the vibration time is too long, the plastic lens is easily damaged if the vibration treatment time is too long. Less vibration processing time means improper processing, and it is impossible to break the plastic lens from the sprue all at once. The vibration processing time is less than 0.29 seconds, and it is impossible to separate all plastic lenses at one time. The vibration processing time is greater than 0.29 seconds, resulting in damage to the surface and edge of the plastic lens. The vibration processing time has been adjusted many times. With a vibration processing time of 0.29 seconds, it takes only one stroke to separate all plastic lenses from the gate.

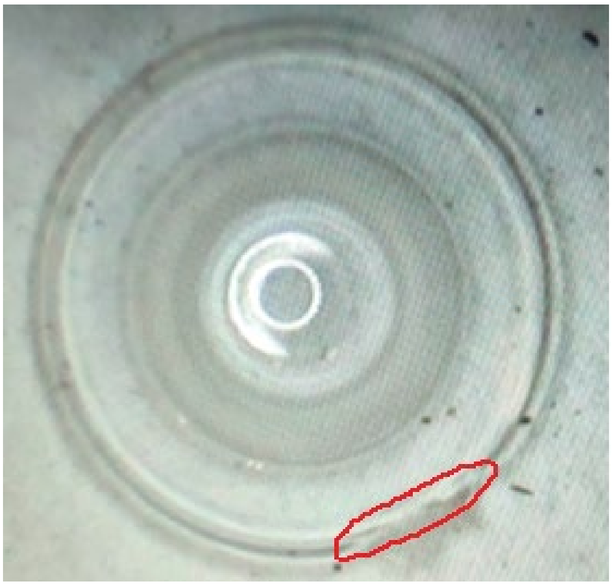

Fig. 9. Plastic lens before tunning Ultrasonic Horn.

The plastic lens after the tunning ultrasonic horn is shown in Fig.10. This is a good result without the damage.

Fig. 10. Plastic lens after tunning Ultrasonic Horn.

The tuning parameters of the designed ultrasonic horn are adjusted by the head-to-tail method. Finding a suitable ultrasonic vibration time can not only avoid excessive vibration but also crush all plastic lenses at one time. After tuning the ultrasonic machine settings, performed the ultrasonic machining operation on the plastic lens in real-time for quality evaluation. Each plastic lens is personally inspected by a microscope. The values, which are tested in real-time after ultrasonic machining operation is shown in Table 4. 120 plastic lenses are tested after performing ultrasonic machining operation, and out of 120 plastic lenses, 109 plastic lenses don't have any scratches and damage, only 11 plastic lenses have small damages on the surface. The quality accuracy of the plastic lens is 90.83%. While the quality accuracy of the plastic lens in the SJ-26a ultrasonic horn only achieved 82.5%.

Table 4. Inspection of the plastic lens by microscope.

Tested number	OK number	NG number	Q (%)
120	109	11	90.83

5. Conclusions

Based on the good stand and horn design. The research completes the separation method and scaffold. With the help of EDM and servo motor, gap voltage, pulse on time, pulse off time, and outlet water pressure, the calculated average position control error of pitch circle diameter is 0.01025 mm. The horn is designed to provide perfect longitudinal vibration movement at 15 KHz frequency. The processing vibration time is very short, and after setting and adjusting the processing parameters, all plastic lenses are crushed at one time. The quality accuracy rate of the plastic lens is 90.83%, and the total processing time is 1.25 seconds.

Author Contributions: conceptualization, NN. Thai and K-C. Lee; methodology, X.X.; software, K-Y. Lu; validation, NN. Thai and GAK. Reddy; formal analysis, NN. Thai, B-E. Liu and GAK. Reddy; investigation, K-Y. Lu and GAK. Reddy; resources, K-Y. Lu and GAK. Reddy; data curation, K-Y. Lu; writing—original draft preparation, NN. Thai, B-E. Liu, K-Y. Lu, GAK. Reddy and K-C. Lee; writing—review and editing, NN. Thai and K-C. Lee; visualization, NN. Thai and BE. Liu; supervision, K-C. Lee. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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