Simulation Development of SFD and SOD Regulating Table Control Systems Using Ultrasonic Sensors

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ABSTRACT
In previous research of non-destructive testing, SFD settings and shifts were carried out with a specimen table connected by ball screw transmission and controlled by a stepper motor. In addition, the input value in the form of SFD is less effective because the operator needs to calculate the minimum SFD value before using the specimen table. The system can only use the calculation of SFD parameter. This study aims to simulate the development of a control system that can adjust the height of the control table to regulate the SFD / SOD using an ultrasonic sensor and compare it to the minimum SFD needed for irradiation. The results of the control system simulation test have featured an ultrasonic sensor that can be used to determine the distance of the test object to the focal spot, thickness/diameter of the test object, and regulate the vertical and horizontal movements of the regulating table. In addition, the control system can determine the suitability of the SFD entered using a matrix keypad with the minimum SFD applicable to a radiography test irradiation. In this research, a simulation has been made to develop a control system using an ultrasonic sensor that can regulate the movement of SFD and ultrasonic sensors so as to determine the minimum SFD of SOD irradiation. The control system can measure plate thickness or pipe diameter with a minimum thickness of 31 mm and a maximum of 140 mm in the SFD method and the SOD method.

Keywords: *Control system, Regulating table, Source to film distance, Source to object distance.*

1. INTRODUCTION

Non-destructive testing or Non-Destruction Test (NDT) has a variety of techniques that are an important part of the world industry in quality control of production processes. Each technique has its advantages and weakness. One of the NDT methods used is the Radiography Test (RT). Radiography test is a testing method that uses an X-ray or Gamma ray source penetrated to the specimen or welding to inspect for defects in the specimen and the results of the shape in the image on the radiography film [1].

RT uses an X-ray plane as a source of X-ray radiation. In general, the X-ray plane consists of three parts, the X-ray tube, the high-voltage source, and the control unit. In the RT test, the focal spot is positioned in corresponding with the geometry setting so that it faces the specimen at a shift and Source to Film Distance (SFD) or Source to Object Distance (SOD). This setting is made to get the quality of a specimen's image in corresponding with applicable standards. In order to obtain a good radiography, the dimensions of the source are made small and the source to film distance (SFD) or the source to object distance (SOD) is adjusted. Since the dimensions of the source in an X-ray plane are fixed, the SFD/SOD setting is important [2].

The method of exposure in the RT technique depends on the shape of the specimen to be tested. Factors affecting RT exposure are exposure time, current for X-rays or activity for gamma rays, and SFD / SOD. Setting the source to film distance as well as the source to object distance and source shift are needed to carry out RT exposure in corresponding with the applicable minimum SFD. A control system is required to regulate the SFD / SOD. The control system is a technology that connects mechanical, electrical and electronic systems together with information systems to control RT exposure [3].

In a previous research [4], SFD adjustment and shifting could be done with a specimen table connected to a jack connected to the screwball and controlled by a stepper motor. The research resulted in a shift in corresponding with the expected input. However, the input value in the form of SFD is less effective because the operator needs to calculate the minimum SFD value that can be used first before using the specimen table. The system can only use the SFD method, not yet the SOD method.

To solve some of these shortcomings an ultrasonic sensor can be used. By calculating the difference between the distance before and after placing the test object, this sensor can be used to measure plate thickness or pipe diameter so that it can determine the minimum SFD for exposure and can be used to determine SFD and SOD. The use of ultrasonic sensors makes SFD setup more efficient. To avoid damage to components when manufacturing the control system, an application can be used to simulate the control system.

Therefore, in this research, a simulation of the development of a control system that can automatically regulate SFD/SOD is created. SFD/SOD is adjusted according to the minimum SFD required in an X-ray radiation using ultrasonic sensors and stepper motors controlled by Arduino. This makes it easier for operators to set up the specimen table

2. METHOD

2.1. Control System Identification

In this research, a problem identified is how to use an ultrasonic sensor to determine the presence and thickness / diameter of the specimen to calculate the minimum SFD by calculating the difference between the distance before and after placing the specimen and how to use the ultrasonic sensor to measure the distance when adjusting the height of the SFD control table and SOD in vertical movement according to the input value from the matrix keypad. This control system uses a constant X-ray plane height of 1250 mm. The height is measured from an X-ray source that is inside the X-ray plane. The initial height of the control table is 500 mm. The control system uses two stepper motors for vertical and horizontal movement as shown in Figure 1. In addition, how to use the input welding width value from the matrix keypad to calculate the required shift distance and perform a horizontal shift of that value. The control system used is shown in Figure 1.

In this research, the control system requires a method of how to measure the initial distance, measure the thickness / diameter of the test object, calculate the SFD / SOD, calculate the shift, vertical movement, and horizontal movement.

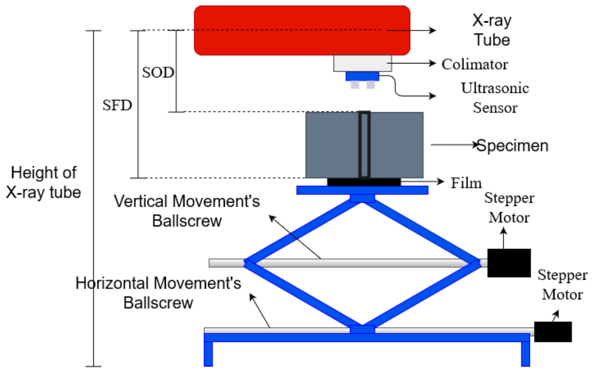


Figure 1. Control system identification.

In this research, the control system requires a method of how to measure the initial distance, measure the thickness / diameter of the test object, calculate the SFD / SOD, calculate the shift, vertical movement, and horizontal movement.

2.2. Initial Distance Measurement

The initial distance measurement is carried out using an ultrasonic sensor. The distance measured based on A.1 is converted into microsecond time units and millimeter length units so that the equation in the program becomes

$$S(mm) = duration(\mu s) \times 0{,}17 mm/\mu s \quad (A.1)$$

In the simulation, the initial distance measurement was carried out using the actual HC-SR04 ultrasonic sensor with a simulation of the control system on the control table. In the Proteus simulation, the distance generated by the ultrasonic sensor comes from changes in the sensor input voltage. The library used in Proteus has a characteristic input voltage that is proportional to the distance the sensor reads. The voltage used for the initial distance is the one that results in a distance approaching 750 mm.

2.3. Thickness Measurement

Thickness measurements were carried out using an ultrasonic sensor. Measurements are made by calculating the difference between the two measured distances. The first distance is the initial distance between the sensor to the table. The second distance is the distance between the sensor and the specimen. The thickness of the specimen is the difference between the two distances which is illustrated in Figure 2. When the specimen is a plate, the measurement result is called the thickness. When the specimen is a pipe, the measurement result is called the diameter.

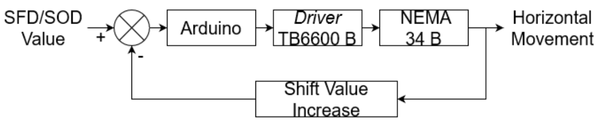


Figure 5. Vertical movement block diagram

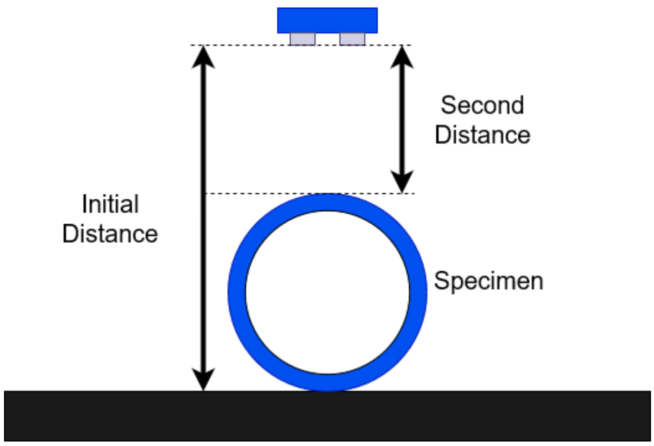


Figure 2. Thickness measurement.

2.4. Minimum SFD Calculating

The minimum SFD calculation is determined in corresponding with A.2 and A.3. While the minimum SOD is determined by A.2 and A.3 and the result of the equation is reduced by the thickness value of the specimen. A.2 is used to calculate the minimum SFD / SOD of plate specimens while A.3 is used to calculate the minimum SFD / SOD of pipe specimens.

$$SFD_{\min} = \left(\frac{f}{UG_{\max}} + 1 \right) X \tag{A.2}$$

$$SFD_{\min} = \left(\frac{f}{UG_{\max}} + 1 \right) OD \tag{A.3}$$

2.5. Shift Movement

The shift calculation is determined according to A.4. The shift calculation uses the welding width value input and the SFD / SOD value input from the matrix keypad. Shifts are only used for pipe specimens. The shifts are illustrated in Figure 3.

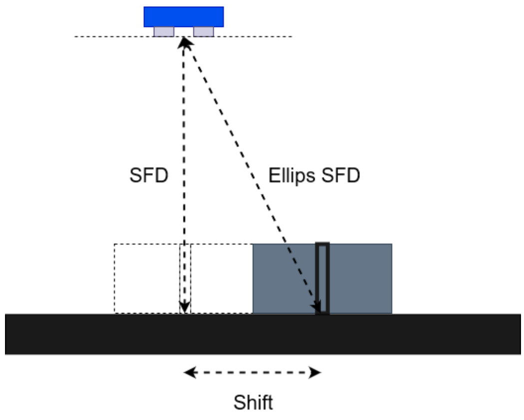


Figure 3. Shift movement.

$$P = \frac{1}{5} SFD + 2L \tag{A.4}$$

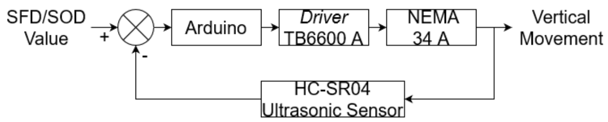


Figure 4. Vertical movement block diagram.

2.6. Vertical Movement

The vertical movement is carried out using a stepper motor rotation so that the table height can change according to the direction of the stepper motor rotation. The block diagram of the vertical movement control system is shown in Figure 4. Based on Figure 4, the SFD / SOD input value from the matrix keypad will be processed by Arduino Uno so that driver A drives the stepper motor A. When the motor rotates, the ultrasonic sensor measures the distance change that occurs. Motor rotation stops when the measured distance from the ultrasonic sensor is less than the input value from the matrix keypad. In the SOD method, the measured distance is the distance between the sensor and the specimen. Whereas in the SFD method the measured distance is the distance between the sensor and the specimen plus the thickness of the specimen. The SFD used is the last value read by the ultrasonic sensor.

2.7. Horizontal Movement

Horizontal movement is carried out using a stepper motor rotation so that the table position can change to the horizontal direction. The block diagram of the horizontal movement control system is shown in Figure 5.

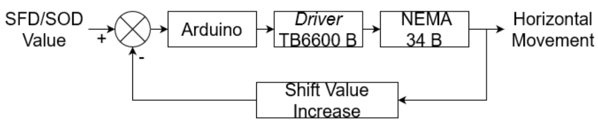


Figure 5. Horizontal movement block diagram.

Based on Figure 5, the input shift value comes from the weld width input entered in Eq. (4). Arduino will send a pulse to driver B so that stepper motor B rotates. Each rotation of the motor will increase the value of the shift that has been done. How far the stepper motor rotation is determined by table specifications, 5 mm / rotation[5] based on the value of the shift calculation. Each rotation of the stepper motor requires 200 pulses from Arduino. The motor rotation stops when the shift value is reached.

2.8. System Block Diagram

The SFD and SOD control table control system using ultrasonic sensors has a system block diagram as shown in Figure 6.

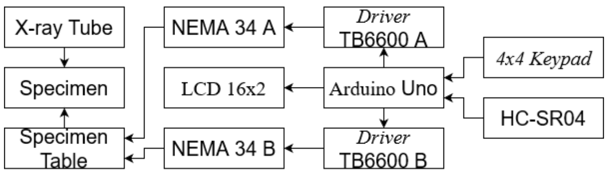


Figure 6. System block diagram.

The control system uses Arduino as a controller as shown in Figure 6. The control system has input in the form of SFD or SOD values as well as weld width from the keypad and the distance value of the specimen and focal spot from the ultrasonic sensor. The output on the system is a 16x2 LCD displaying the SFD / SOD value or the thickness of the specimen and the output pulse to the driver that controls the motion of the stepper motor. The stepper motor moves the specimen table and the specimen which is located on it. The movement of the stepper motor is affected by the ultrasonic sensor and / or calculations in the program. The specimen will be illuminated by an X-ray plane through the focal spot.

2.9. Control System Schematic Diagram

The control system has relation between components such as the schematic diagram in Figure 7. Based on Figure 7, it can be seen that several components are connected to Arduino. The 4x4 matrix keypad is connected to digital pins 2-9, the A4988 motor driver is connected to digital pins 10-13, the I2C and 16x2 LCD modules are connected to analog pins 4 as SCL pins and 5 as SDA pins and VCC and GND pins, while the HC-SR04 ultrasonic sensor is connected to analog pins 1 and 2 as well as VCC and GND pins.

The A4988 motor driver is connected to the Nema 34 stepper motor. In addition, the motor driver is also connected to the power supply connected to the power supply.

2.10. Program Flowchart

The control system has commands that are executed in corresponding with the control system flow chart in Figure 7.

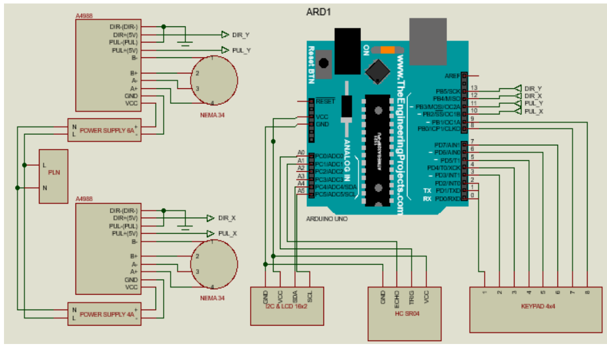


Figure 7. Control system schematic diagram.

The control system program flow diagram is shown in Figure 8. The control system program begins by reading the distance using an ultrasonic sensor between the specimen and the focal spot of the X-ray tube as the initial distance. If the specimen is placed, there is a change in the initial distance. This change resulted in the control system displaying the SOD method. However, if there is no change in distance at a certain time, the control system will display the SFD method.

The SOD method will input the SOD value used.

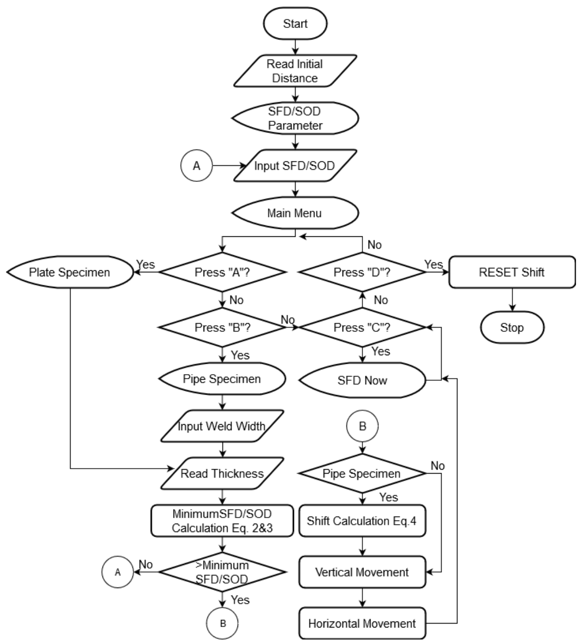


Figure 8. Control system flowchart

Then a menu of options is displayed to press the "A", "B", "C", or "D" button on the matrix keypad. The "A" button functions to select the specimen in the form of a plate. The plate thickness determines the minimum SOD that applies to the exposure. Input the SOD value using the matrix keypad will be compared with the minimal SOD. If the SOD value is less than or equal to the minimum SOD, then the SOD value is rejected and will return to the input command until the SOD value matches. On the specimen the stepper motor plate is active so that vertical movement occurs. The "B" button is used to select the specimen in the form of a pipe. In the specimen, the control system pipe requires the input of the weld width to calculate the horizontal movement value. Control system reads plate thickness. The plate thickness determines the minimum SOD that applies to the exposure. Input the SOD value using the matrix keypad will be compared with the minimal SOD. If the SOD value is less than or equal to the minimum SOD, then the SOD value is rejected and will return to the input command until the SOD value matches. The control system calculates the shift value based on the input value of the weld width and the SOD used. Then, the control system will make a vertical movement and then make a horizontal movement.

In the SFD method, input SFD values are carried out via a matrix keypad. The control system displays a menu of options. The "A" button is used to select the plate specimen. After that the control system reads the plate thickness with an ultrasonic sensor. The control system will determine the minimum SFD value. If the SFD value is less than the minimum SFD value, then enter the SFD value again until it is appropriate. On the specimen the stepper motor plate is active so that vertical movement occurs. "B" button is used to select pipe specimen. In the specimen, the control system pipe requires the input of the weld width to calculate the horizontal movement value. After that the control system reads the pipe thickness with an ultrasonic sensor. The control system will determine the minimum SFD value. If the SFD value is less than the minimum SFD value, then input the SFD value again until it is appropriate. The control system calculates the shift value based on the input value of the weld width and the SFD used. Then, the control system will make a vertical movement and then make a horizontal movement.

The "C" button is used to display the SFD / SOD being used. On the plate specimen, SFD is calculated from the distance that the ultrasonic sensor reads plus the thickness of the specimen. Meanwhile, SOD is calculated from the distance that the ultrasonic sensor reads. For pipe specimens, SFD is calculated from the Pythagoras formula from the distance read by the ultrasonic sensor plus the thickness of the specimen and the value of the shift. Meanwhile, SOD is calculated from the Pythagoras formula from the distance read by the ultrasonic sensor and the shift value. "D" button to shift RESET which is used to return the control table to its original position.

2.10. Operator Flowchart

The SFD / SOD control table control system is used by the operator. The operator sets up the control table by carrying out the steps on the operator flow chart shown in Figure 9.

The operator starts the control system. If the operator uses the SFD method, the operator enters the SFD value on the matrix keypad. If the operator uses the SOD method, the operator places the test object on the control table then enters the SOD value on the matrix keypad. After that, if the specimen that the operator will use is a plate, the operator will press the "A" button. If the method being used is SFD, the operator places the plate specimen and finishes. If the SOD method, the set up process is complete. Then the operator waits until the control system has finished adjusting the SFD / SOD distance. If the specimen that the operator will use is a pipe, the operator will press the "B" button. The operator enters the weld width value on the matrix keypad. If the SFD method is used, the operator will place the specimen. If the SOD method is complete, the operator waits for the control system to adjust the SFD / SOD distance.

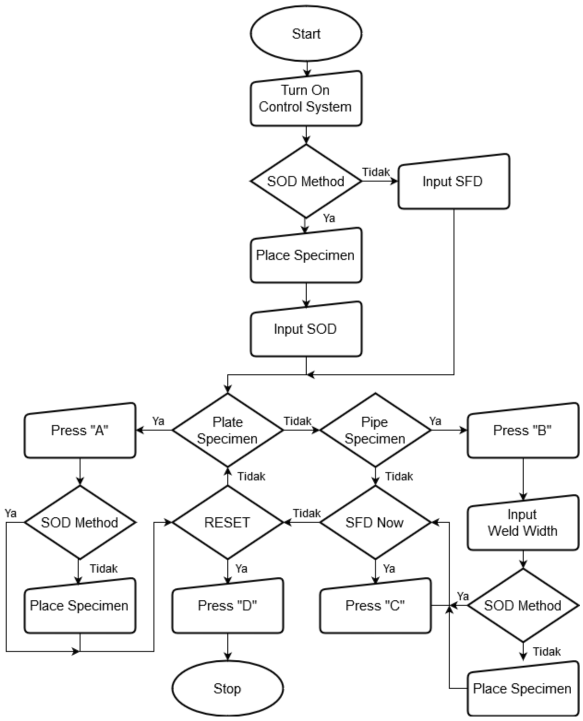


Figure 9. Operator flowchart

After that, the operator can see the current SFD value by pressing the "C" button. The operator returns the setting table to the starting position by pressing the "D" button.

2.12. Control System Program

Making control system programs using the Arduino IDE application. Writes the program that will be used for the control table. The program is divided into two parts. The first part is the void setup and the second part is the void loop. Initialization of libraries and declarations of variables and pins used in the program. The void setup section will be executed once after Arduino is turned on. The void loop will be executed continuously as long as Arduino is still on.

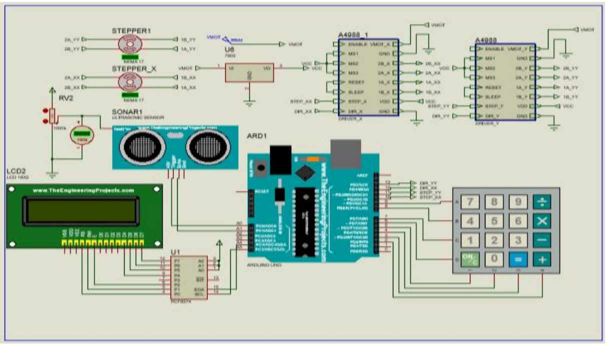


Figure 10. Control system simulation.

2.13. Control System Simulation

Making control system simulation using the Proteus 8.6 Professional application. The circuit used is shown in. Simulation requires. hex control system program file and ultrasonic sensor.

2.14. Control System Test

The initial table distance measurement test is carried out by taking the table distance data from the X-ray plane as measured by the ultrasonic sensor. The distance data is the initial SFD value on the regulating table. The distance data is replaced by a voltage which is converted into a distance.

Thickness measurement test is carried out by collecting data on the thickness of the specimen as measured by an ultrasonic sensor. The distance data is the difference between the distance data before and after the specimen is placed on the distance control table which is replaced by the difference in voltage at the ultrasonic sensor input before the initial distance value is displayed and after the input voltage is changed.

Vertical Movement Test is carried out by collecting vertical movement data. The vertical movement data is the distance value read by the ultrasonic sensor and compared with the SFD / SOD input value.

Horizontal movement data test is carried out by taking the shift data generated from the control system. Horizontal movement data in the form of rotation will be converted into a distance based on the mechanical system specifications compared to the displacement value.

2.14. Analysis Method

The research results were analyzed using quantitative data analysis methods. The analysis was carried out on the Root Mean Square Error A.5 contained in the research results. This analysis was conducted to determine the level of error in the research results. The analysis was carried out by the distance data generated by the ultrasonic sensor on SFD input, horizontal movement to A.4 and vertical movement to A.2 and A.3.

$$RMSE = \sqrt{\frac{\sum (z - z')^2}{n}} \qquad \text{(A.5)}$$

3. RESULT AND DISCUSSION

The simulation of the SFD / SOD distance control table control system uses a voltage that can be adjusted with a pot as an ultrasonic sensor input. This voltage replaces the distance measured by the ultrasonic sensor. Several potentials are used so that they can adjust the input voltage with a small voltage step. The PCF8574 IC is used as a 16x2 LCD I2C module. The motor driver used is the A4988 driver producing a maximum current of 2.0 A. The NEMA 34 stepper motor can rotate with a current of 0.5 A.

Based on the simulation, the control system can measure the initial distance and distance control table by applying voltage to the ultrasonic sensor. The control system can measure the thickness of the plate specimen or measure the diameter of the pipe specimen by adjusting the input voltage on the ultrasonic sensor. The thickness of the specimen is obtained by providing a difference in the input voltage to the ultrasonic sensor. This thickness can determine the minimum SFD / SOD value. If the SFD / SOD input value is less than the minimum SFD / SOD value, the control system will again require an SFD / SOD input value that exceeds the minimum SFD / SOD value. SFD / SOD input values have a limit from 150 mm to 750 mm. The control system can determine the test object used, both plate and pipe.

In the simulation, vertical movement is carried out by moving a stepper motor for vertical movement. When the stepper motor moves, the control table is simulated up so that the distance to the ultrasonic sensor decreases. Reducing the voltage on the ultrasonic sensor input when the motor is moving makes the distance the ultrasonic sensor reads less. The vertical movement stops when the voltage value at the ultrasonic sensor input is changed so that the ultrasonic sensor reads a distance less than the used SFD / SOD value.

Horizontal movement is carried out by the control system by moving the stepper motor to the right for horizontal movement with the number of turns in corresponding with the shift resulting from the input of the weld width value. The horizontal movement stops when the number of turns is reached.

In addition, the control system can display the SFD / SOD in use after the distance adjustment process is complete. So that it can be seen the suitability of the input with the control system output. The control system can be reset so that the stepper motor for vertical movement so that the control table moves downward and horizontally rotates in the opposite direction / to the left with the same amount as when setting. Reset will return the table to the original position before the adjustment was made.

3.1. HC-SR04 Ultrasonic Sensor Calibration

Calibration is carried out by measuring at several distances of the specimen. Measurements are made to determine the accuracy of the distance measured by the sensor. After that, adjustments are made to the program so that the sensor can measure the distance with a smaller error. The distance measurement data by the sensor is shown in Table 1.

Table 1. HC-SR04 Ultrasonic Sensor Calibration

No.	Distance (mm)	Before Calibration (mm)	After Calibration (mm)
1	100	88	91
2	200	181	194
3	300	274	289
4	400	367	392
5	500	467	496
6	600	556	598
7	700	659	695
8	800	752	797
9	900	846	909
10	1000	948	1007
Mean	550	513,8	546,8
Error	-	37,28 mm	6,97 mm

Based on Table 1, it can be seen that after the sensor calibration is carried out, the resulting error value in the measurement is reduced. This resulted in the sensor measurement results representing the true distance. Adjustments made to the program during the calibration process are also used in application simulations, so that the resulting distance in the simulation matches the actual distance.

3.1. Initial Distance Data

The initial distance data is obtained by measuring from a height of 750 mm as required by the SFD / SOD control table control system. The initial distance simulation data is shown in Table 2.

Table 2. Initial distance test data

No.	Real Distance (mm)	Initial Distance (mm)	Height of X-ray Tube (mm)
1	750	750	1250
2	750	754	1254
3	750	754	1254
4	750	754	1254
5	750	754	1254
6	750	750	1250
7	750	754	1254
8	750	755	1255
9	750	750	1250
10	750	750	1250
11	750	755	1255
12	750	755	1255
13	750	754	1254
14	750	754	1254
15	750	755	1255
16	750	754	1254
17	750	754	1254
18	750	754	1254
19	750	754	1254
20	750	755	1255
Error		3,88	3,88

The height of the X-ray tube is the initial distance plus 500 mm. It can be seen that the measurement error for the initial distance and the height of the X-ray tube based on Eq. (1) is 3.88 mm.

The control system requires an input voltage on the ultrasonic sensor resulting in an initial distance of 750 mm. Therefore, data collection was carried out around the input voltage value which resulted in a distance of 750 mm in the Proteus application simulation as shown in Table 3.

Table 3. Initial distance measurement data

No.	Voltage (mV)	Initial Distance (mm)	Height of X-ray Tube (mm)
1.	300	660	1160
2.	305	671	1171
3.	310	682	1182
4.	315	693	1193
5.	320	703	1203
6.	325	714	1214
7.	330	734	1279
8.	335	745	1245
9.	336	745	1245
10.	337	745	1245
11.	338	745	1245
12.	339	745	1245
13.	340	756	1256
14.	345	767	1267
15.	350	821	1321

The mechanical system in the control table control system has an initial height of 500 mm and an X-ray tube height of 1250 mm. Therefore, an input voltage is needed which results in a distance close to 750 mm which is used as the initial distance in the control system. In Table 3, the voltage data is 335 mV which results in a distance of 745 mm. The distance generated by the ultrasonic sensor is not exactly 750 mm. This is because the ultrasonic sensor converts the voltage into a distance with a minimum difference of 5 mV. The difference in voltage is less than 5 mV, the ultrasonic sensor will read the same voltage. This can be seen at a voltage of 335-339 mV. So that when the voltage is increased to 340 mV, the ultrasonic sensor produces a distance of 767 mm.

3.3. Plate Thickness/Pipe Diameter Data

Plate thickness / pipe diameter data is obtained by providing a voltage difference to the ultrasonic sensor. Calculation of minimum SFD / SOD value is based on Eq. (2) with 13 mm plate specimen and based on Eq. (3) with 106 mm pipe specimen as follows. The data on plate thickness / pipe diameter using the SFD method is shown in Table 4.

Table 4. SFD method thickness/diameter test data

Specimen Thickness (mm)	Simulation Thickness (mm)	Simulation Minimum SFD (mm)	Proteus Thickness (mm)	Proteus Minimum SFD(mm)
13	12,8	67	-	-
55	58	230	53	208
85	87	279	86	275
106	104	236	107	241

Based on Table 4, it can be seen that the control system can measure plate thickness / pipe diameter using the SFD method. The simulation can measure a test object with a thickness of 13 mm with an error of ± 1.8 mm, at a thickness of 55 mm it has an error of ± 3.7 mm, at a thickness of 85 mm with an error of ± 2.0 mm, and at a thickness of 106 mm with an error of ± 2.6 mm. Whereas in the simulation Proteus cannot measure a thickness of 13 mm. Minimum usable thickness is 31 mm. Proteus simulation can use a thickness close to 55 mm, namely 53 mm, at a thickness of 85 mm you can use 86 mm, and at a thickness of 106 mm you can use a thickness of 107 mm to simulate the control system.

Plate thickness / pipe diameter data is obtained by providing a voltage difference to the ultrasonic sensor. The plate thickness / pipe diameter data using the SOD method are shown in Table 5.

Table 5. SOD Method Thickness/Diameter Test Data

Specimen Thickness (mm)	Simulation Thickness (mm)	Simulation Minimum SOD (mm)	Proteus Thickness (mm)	Proteus Minimum SOD (mm)
13	12,8	57	-	-
55	54	157	53	155
85	86	188	86	189
106	104	131	107	134

Based on Table 5, it can be seen that the control system can measure plate thickness / pipe diameter using the SOD method. The simulation can measure a test object with a thickness of 13 mm with an error of ± 2.2 mm, at a thickness of 55 mm it has an error of ± 1.9 mm, at a thickness of 85 mm with an error of ± 1.3 mm, and at a thickness of 106 mm with an error of ± 1.5 mm. Whereas in the simulation Proteus cannot measure a thickness of 13 mm.

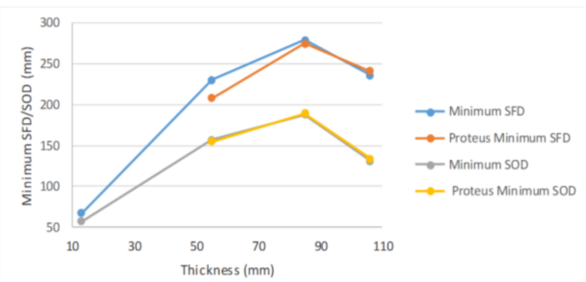


Figure 11. Minimum SFD/SOD comparison.

Based on Table 4 and Table 5, a graph can be made so that the minimum SFD / SOD difference can be used at certain thickness values. The comparison between the SFD method and the SOD method in the control system simulation is shown in Figure 11.

Based on Figure 11, it can be seen that the minimum SFD and minimum SOD used on specimens with a certain thickness have different values. The difference is in the ultrasonic sensor distance measurement. In the SFD method, the measurement of the SFD value comes from the distance value measured by the ultrasonic sensor plus the thickness of the test object. Whereas in the SOD method, the measurement of the SOD value comes from the distance value measured by the ultrasonic sensor only. So that the SOD value used is lower than the SFD value. There is a difference between the minimal SFD / SOD generated from

Proteus simulations and simulations. This is because in the simulation there is an error value in the ultrasonic sensor measurement.

At the thickness of the specimen 106 mm, there was a decrease in the minimum SFD and minimum SOD values. This happens because there are differences in the Ugmax value in Eqs (2) and eqs (3). The thickness of the specimen more than 100 mm has an Ugmax value of 1.75 mm. Because the divider value is large and the thickness is large, it results in a smaller minimum SFD and SOD value.

3.4. Vertical Movement Data

The vertical movement test data shows the distance value measured by the ultrasonic sensor when the stepper motor stops. The vertical movement data in the SFD method using a plate specimen with a thickness of 64 mm is shown in Table 6.

Table 6. SFD method vertical movement test data

Input SFD (mm)	Simulation SFD (mm)	Proteus SFD (mm)	Simulation SOD (mm)	Proteus SOD (mm)
300	299	279	299	294
400	398	391	398	381
500	499	488	498	500
600	599	597	599	589

Based on Table 6, it can be seen that the vertical movement stops after the ultrasonic sensor measures a distance less than the SFD / SOD input value. At the SFD / SOD input of 300 mm, there is an error of ± 1.8 mm in the SFD method and ± 1.4 mm in the SOD method, at the input of 400 mm there is an error of 2.1 mm in the SFD method and of ± 2 , 5 mm in the SOD method, at the 500 mm input there is an error of ± 1 mm in the SFD method and ± 1.7 mm in the SOD method, at the 600 mm input there is an error of ± 0.5 mm in the SFD method and of ± 1 , 2 mm on the SOD method.

The vertical movement does not match the distance specified by the SFD value. This difference occurs because in the simulation of Proteus 8.6 Professional HC-SR04 ultrasonic sensor cannot respond to input voltage differences of less than 5 mV. So that the control system will stop the rotation of the stepper motor if the distance value measured by the ultrasonic sensor is less than / equal to the SFD input value.

In the simulation there is a difference between the SFD / SOD input and the simulation SFD / SOD. This happens because the specimen is moved manually by hand. Hand movement does not match the speed of movement on the control table mechanical system so that the distance that the ultrasonic sensor reads is less than the input. The results of the simulated vertical movement are better than the vertical movement in the Proteus simulation because the resulting SFD / SOD has a smaller error than the Proteus simulation.

3.4. Horizontal Movement Data

Horizontal movement test data obtained the distance value generated by the rotation of the stepper motor according to the shift value. The calculation of the displacement value with the input weld width is based on Eq. (4) on the SFD and SOD methods with an input SFD value of 500 mm and a weld width of 5 mm as follows.

Simulated horizontal movement data with 106 mm specimen and 500 mm SFD values are shown in Table 7.

Table 7. Simulation SFD method horizontal movement test data

Weld Width (mm)	Shift (mm)	Motor Rotation	Horizontal Movement (mm)	Simulation SFD (mm)	Ellips SFD (mm)
5	110	22	110	499	510
10	120	24	120	498	512
15	130	26	130	500	516
20	140	28	140	499	518
25	150	30	150	500	522
30	160	32	160	498	523

The horizontal movement data for Proteus simulation on the SFD method using a pipe specimen with a thickness of 107 mm and an SFD value of 500 mm are shown in Table 8.

Table 8. Proteus SFD method horizontal movement test data

Weld Width (mm)	Shift (mm)	Motor Rotation	Horizontal Movement (mm)	Proteus SFD (mm)	Ellipse SFD (mm)
5	110	22	110	488	500
10	120	24	120	488	502
15	130	26	130	488	505
20	140	28	140	488	507
25	150	30	150	488	510
30	160	32	160	488	513

Based on Table 7 and Table 8, it can be seen that the control system can calculate the shift value based on the weld width input. The greater the weld width, the greater the shift value. The distance after the stepper motor rotation corresponds to the shift value. After the horizontal movement, the ellipse SFD value is obtained. The elliptical SFD value corresponds to the SFD value and the displacement value calculated using the Pythagoras formula. The elliptic SFD values in the two tables are different due to the different SFD values when the vertical movement stops.

Table 9. Simulation SOD method horizontal movement test data

Weld Width (mm)	Shift (mm)	Motor Rotation	Horizontal Movement (mm)	Simulation SOD (mm)	Ellips SOD (mm)
5	132	26.4	132	499	516
10	141	28.2	141	500	519
15	151	30.2	151	500	522
20	162	32.4	162	499	524
25	171	34.2	171	500	528
30	181	36.2	181	500	531

Table 10. Proteus SOD Method Horizontal Movement Test Data

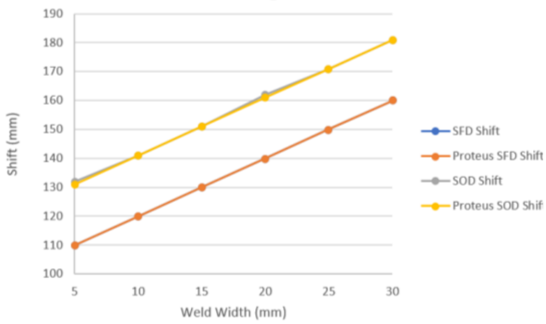
Weld Width (mm)	Shift (mm)	Motor Rotation	Horizontal Movement (mm)	Simulation SOD (mm)	Ellipse SOD (mm)
5	132	26.4	132	499	516
10	141	28.2	141	500	519
15	151	30.2	151	500	522
20	162	32.4	162	499	524
25	171	34.2	171	500	528
30	181	36.2	181	500	531

The motor rotation is converted to horizontal movement by multiplying by the mechanical system conversion value, which is 5 mm / rotation. So that the horizontal movement value is obtained according to the shift value. The horizontal movement data for the SOD method using a pipe specimen with a thickness of 107 mm and a SOD value of 500 mm in the simulation are shown in Table 9.

The horizontal movement data on the SOD method using a pipe specimen with a thickness of 107 mm and a SOD value of 500 mm are shown in Table 10.

Based on Table 9 and Table 10, it can be seen that the control system can calculate the shift value based on the weld width input. The relationship between the two tables is shown in Figure 12.

Figure 12. Shift value comparison.



Based on Figure 12 it can be seen that the greater the value of the weld width, the greater the shift value. The distance after the stepper motor rotation corresponds to the shift value. After the horizontal movement, the SOD value of the ellipse is obtained. The elliptic SOD value corresponds to the SOD value and the shift value calculated using the Pythagoras formula. The elliptical SFD values in the two tables are different due to the different SFD values when the vertical movement stops.

The motor rotation is converted to horizontal movement by multiplying by the mechanical system conversion value, which is 5 mm / rotation. So that the horizontal movement value is obtained according to the shift value.

4. CONCLUSION

Based on the results of the discussion in Chapter IV, it can be concluded as follows. A simulation of the development of a control system that can regulate SFD or SOD using ultrasonic sensors has been made. The control system performs vertical movement if the test object is a plate. The control system performs vertical movement and horizontal movement if the specimen is a pipe. The control system Proteus simulation can use a plate / pipe specimen with a minimum thickness of 31 mm with a minimum SFD of 167 mm / SOD of at least 136 mm. While the control system simulation can use a plate / pipe specimen with a minimum thickness of 13 mm with a minimum SFD of 67 mm with an error of ± 1.8 mm or a minimum SOD of 57 mm with an error of ± 2.2 mm.

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