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DEVELOPMENT OF ANTENNA POSITIONER

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ABSTRACT

This paper describes the procedures to develop a low cost linear z-traverse antenna positioner. The positioner was designed using a PCI-ADC data acquisition card and its analog to digital controller (ADC). The platform of the positioner is moved by dc motor as an actuator where its movement is sensed and feedback through an absolute contacting rotary encoder. Software was developed to acquire, analyze and display the data and the output will be calculated through PID controller embedded in the software. The controller was uniquely tuned by the aid of simulation to suit the application. The whole system was then tested and calibrated. Based on calibration data, the system was optimized to produce better accuracy via correction through software compensation. The whole knowledge on designing a low cost positioner both theoretical and practical was acquired.

Keywords: *Antenna Positioner, Motion Control, PID, System Optimization*

1.0 INTRODUCTION

With the rapid growth of novel antenna architectures, it is essential to characterize the antenna radiation characteristics accurately. Antenna and electric field probe calibration requires precise positioning and movement throughout a known RF field [1]. This is because the universally accepted form of antenna data is in the complete radiation pattern. The patterns or characteristics of the antennas are obtained by sampling the electric field over the space around the antennas. The sampling should be acquired around the antenna for its radiated energy. In practice, the radiation pattern can be obtained by recording the signal received by an antenna under test (AUT) through its motion while the probe antenna is kept stationary [2]. All these testing and calibration require precise, accurate positioning and orientation. The value of the exposure field is determined as a function of position in space relative to the transmitting antenna. When the test frequencies increased, wavelengths decreased. As a result, the required positional accuracy of the AUT becomes tighter. Consequently, a precise and accurate antenna positioner is required for antenna testing and calibration [1].

2.0 TYPICAL ANTENNA POSITIONER

Figure 1 is the basic configuration of an antenna testing instrument. It consists of a positioner and a controller that can move the AUT to the desired position [3]. Generally, to get a good result from the sampling, it is required that the platform and the positioning mechanism should not generate reflection and absorption to the antenna's signal. Consequently, the amount of material used for the positioning system should be minimized [2]. The instrument is a combination of several systems. It cannot work by itself without depending on the others. Practically, almost the entire instrument nowadays is a combination of hardware (computer system, mechanical system, electronic system and measurement system), software (algorithm for data acquisition or input, output from computer after going through iterations of control algorithm and graphical user interface) and control system (control algorithm).

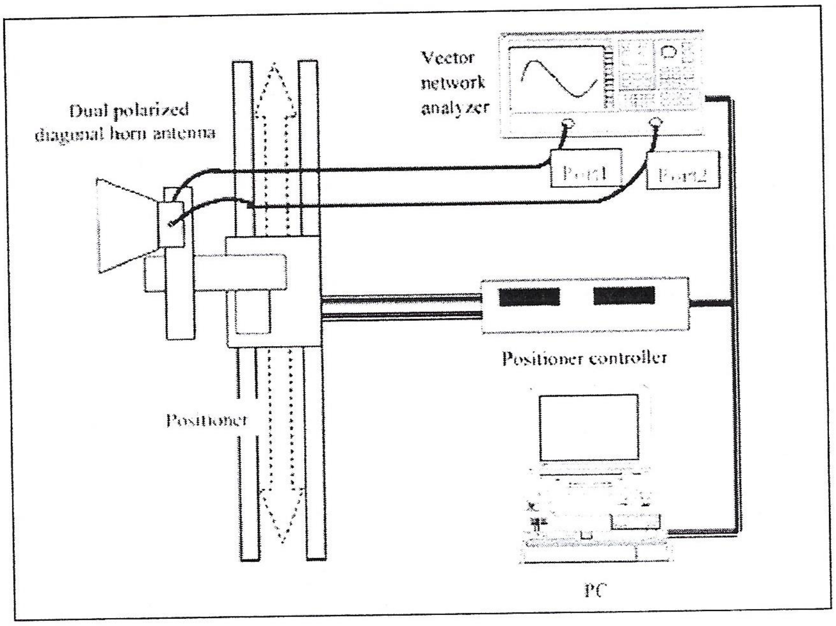

Figure 1: Configuration of an antenna testing instrument

Figure 2 illustrates the design layout of a positioner in an antenna measurement system shown in block diagram. This is the design layout of this research where the AUT connected to a receiver is placed on the platform of the positioner that transverses in z-axis. The platform is moved by an actuator. The actuator is controlled by a computer as the controller that contains a sensor as a feedback to obtain information back to the console (computer). The information from the sensor is used as position indicators which allow the operator to know the orientation of the test antenna and to calculate the coordinate of the antenna pattern [4].

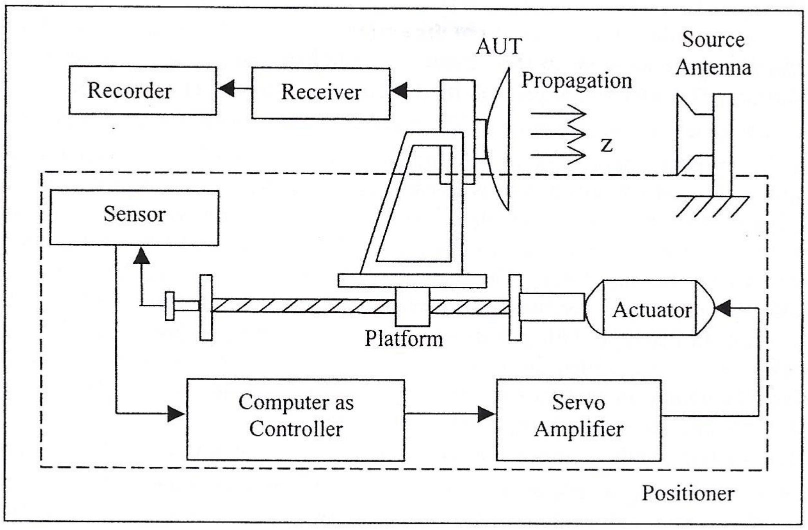

Figure 2: Typical block diagram of a positioner in an antenna measurement system

3.0 MECHANICAL SYSTEM

The research mainly focused on implementing lead screw and nut as the power transmission system. Due to the effect of wear and tear when two materials are sliding over each other, they need maintenance. Thus, the nut is made by softer material compared with the lead screw since the nut is smaller and easier to replace. Both lead screw and nut are fabricated in the form of acme thread. One end of the lead screw is driven by sprocket and roller chain. Although nonlinear characteristic did exist in the sprockets and roller chain system, they do not affect the performance in term of accuracy at all. The sprockets work in pair and another piece of sprocket is connected by a reduction gear (worm gear) which is driven by dc motor. The purpose of the reduction gear is to reduce the output speed and at the same time increase the torque to drive the heavy load. It is designed in the type of worm gear because very high gear ratio will make the power to flow only one way. Thus the power train will have lockup property. This is important in term of precision since it locks the platform of the positioner in certain position after the platform is moved and stopped at particular position. The designed sprocket and worm gear has the property of reduction in the ratio of 11/1265.

4.0 MEASUREMENT SYSTEM

At the other end of the lead screw, a sensor (absolute contacting rotary encoder) is connected to sense the movement of the system. In order to reduce the resolution of the system, a reduction gear was added in this research. There are two techniques to reduce the resolution of the system. The first technique is by adding a reduction gear as done in this research or implementing a sensor with better resolution. But this technique has its deficiency. When it is connected with a reduction gear with gear ratio $17/32$, the sensor will rotate approximately two time the speed compared to its original design. This will tend to reduce the sampling time which will normally burden the computer processor or the system will fail to obey Shannon's sampling theorem. The only way to cope with these problems is to tune the system to operate in slower speed until the computer is able to acquire the input data. The second technique which is more desirable is by modifying the existing hardware. The resolution can be reduced by changing the lead screw to the type with a smaller pitch. This technique does not affect the sampling time and burden the processor of the computer but it involves a large amount of money in fabrication. However, due to costing control, the existing lead screw and the first technique were employed.

The system needs a sensor that can trace up to an accuracy of $30\mu m$. The criteria in choosing a sensor are: provide real-time measurement with minimum acceptable error, inexpensive, compact, easy to mount to lead screw, durable, digital output, sturdy and flexible. Thus, absolute contacting rotary encoder from BOURNS was considered as it met all the criteria. The encoder produces 8-bit gray codes with 128 absolute positions in a revolution. Although it is contacting encoder, it can sense up to 120rpm rotating speed which is faster than the system operating speed. It also can rotate continuously to trace position more than a revolution. The lead screw needs around 300 revolutions to displace the platform from 0 to $1.7m$. An absolute encoder was chosen instead of incremental encoder because it provides absolute digital outputs that can be recognized and traced easily as a reference in future calculation in control algorithm. The encoder is able to provide real time measurement as long as the 50-way rainbow cable (signal line) from the sensor to PCI-ADC interface card does not exceed 10 m. The sampling time of the sensor is $1ms$. It is mounted together with a coupling for the alignment purpose.

5.0 ELECTRICAL SYSTEM

There are mainly three types of motor driver; the on/off relay circuit, pulse width modulation (PWM) motor driver and analog driver. The on/off relay circuit is not suitable because it could only give a constant output and does not satisfy the application as a PID controller. The PWM technique is not suitable due to the possibility of generating radio frequency interference (RFI). This is critical since the RFI may interrupt and affect antenna propagation during testing of antenna. Thus, an analog driver is the most suitable circuit to drive the motor.

The selected dc motor requires a power supply that can deliver $\pm 15V$ and provide enough current to produce enough torque to drive the heavy load. Therefore a power supply with Darlington transistor pairs was designed. The circuit of the whole system is as illustrated in Figure 3. For safety reason, limit switches were equipped to stop the system when the platform reaches both ends of the rail to prevent damage on the mechanical system.

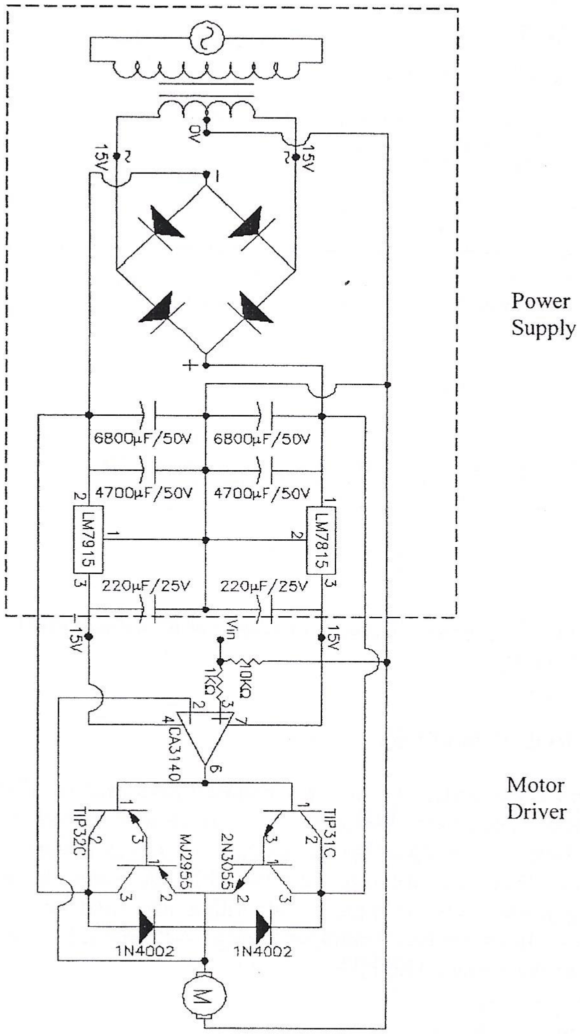

Figure 3: Power supply and motor driver circuit

The whole mechanical, electrical and measurement system form a block diagram as shown in Figure 4. Figure 5 is the block diagram that represents the system.

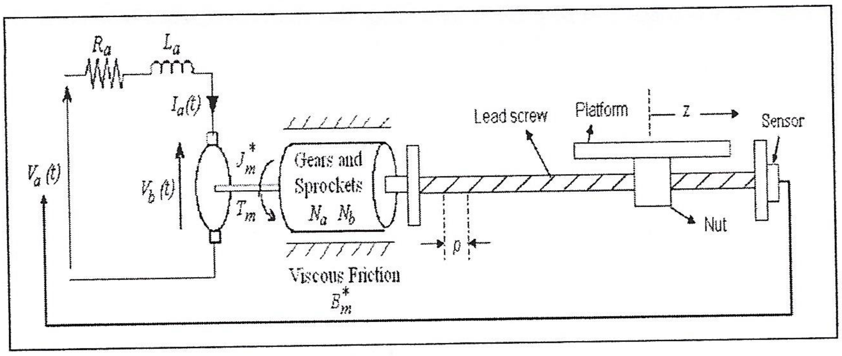

Figure 4: Block diagram of the system

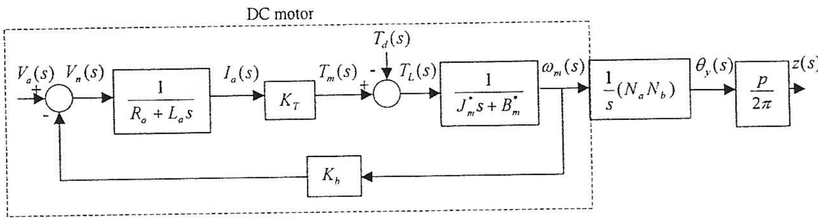

Figure 5: Open loop block diagram of the system in mathematical transfer function

6.0 CONTROL STRATEGY

In order to control the system to meet the required performance, PID controller was implemented. The digital PID algorithm was chosen instead of the analog PID algorithm because the algorithm in software is easy to change according to the applications. There are two types of digital PID algorithm, an absolute and incremental algorithm. The incremental algorithm was used since it has anti-windup features. It also solves bumpless transfer problem [5]. Figure 6 is the block diagram of the system with PID controller.

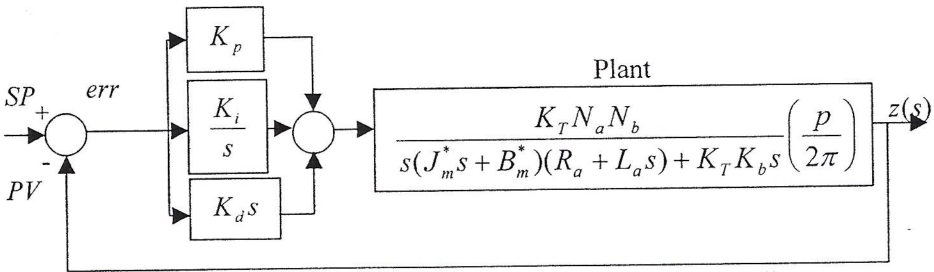

Figure 6: Block diagram of the close-loop system with PID controller

Although there are many types of finite differential approximation, derivation in equation 1 was implemented. It is a PID control algorithm using trapezoidal rule of integral term and backward differences approximation to derive proportional and derivative terms [6]. This algorithm will yield a more accurate output.

$$\begin{aligned}\Delta u_i &= K_p\left[\Delta e_i + \frac{1}{2T_i}(e_{i-1}+e_i)T + K_d(\Delta e_i - \Delta e_{i-1})\right]\\ &= K_p\left[(e_i - e_{i-1}) + \frac{1}{2T_i}e_i T + K_d\left(\frac{e_i - e_{i-1} - (e_{i-1} - e_{i-2})}{T}\right)\right]\\ &= K_p\left[(e_i - e_{i-1}) + 0.5K_i T(e_{i-1}+e_i) + \frac{K_d}{T}(e_i - 2e_{i-1} + e_{i-2})\right]\end{aligned} \quad (1)$$

7.0 GRAPHICAL USER INTERFACE (GUI)

In order to make the system become a user friendly instrument, a GUI has been designed as illustrated in Figure 7. It was designed in an easy to use and comprehensive way to ease the user to operate the system in variable operating mode. There are Manual and Auto control systems. In the manual system, the user can move the positioner to the desired position by just moving the slider in the GUI to move the positioner manually. There are three modes in Auto system, i.e.

a. Mode 1: Single point setting.
b. Mode 2: Displacement single point setting.
c. Mode 3: Absolute multipoint setting.

Single point setting is a mode for the user to key in absolute value. The purpose of this mode is to move the antenna to the specified position directly. Mode 2 is required when the user wants to displace the platform in some specified distance measured from the current position. Absolute multipoint setting is the mode chosen when the user wants to test the antenna in several positions and each position has the same distance with its adjacent positions. In order to enhance the function of the control system, a recess time function is added for the user to specify the required time the platform recesses at starting position, each interval break and ending position. The platform will automatically move forward or reverse when recess time is over in that particular position.

Besides, a user may update the information of the antenna in another GUI as illustrated in Figure 8. With flexible data display and data saving features, the data can be analyzed and saved for further analysis effortlessly.

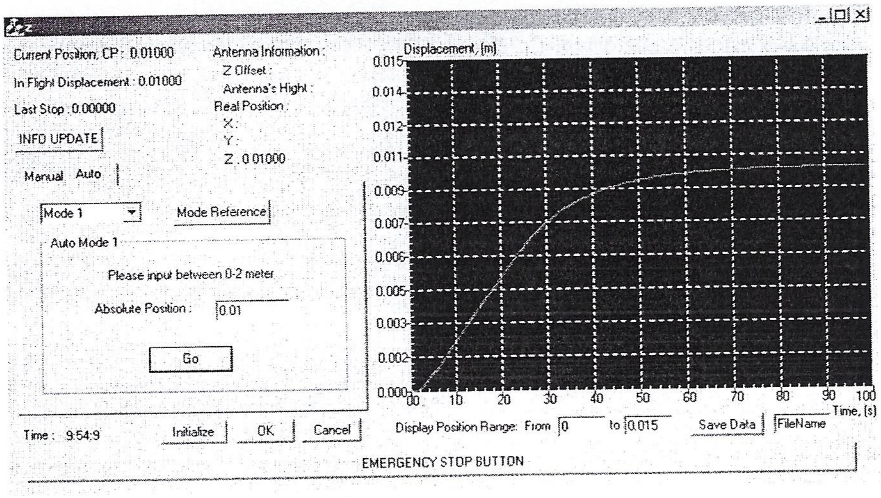

Figure 7: GUI model

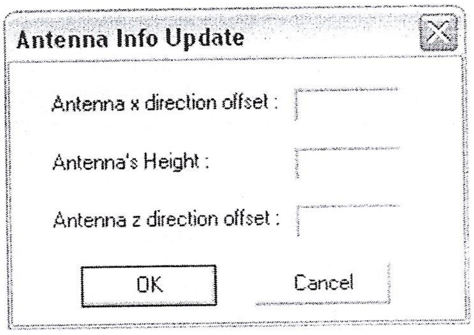

Figure 8: Antenna info updates pop up dialog box

8.0 SIMULATION

MATLAB® was used to simulate the whole system with different configuration with the intention to predict the stability of the system. It was used to view the response of the system in term of settling time, overshoot, unwanted oscillations and steady state error. It also helped to verify the theories employed to investigate its dynamic performance. Through the technique of simulation, the process of predicting and acquiring PID controller gains was much easier than extensive test of the real system. Simulation model was designed in SIMULINK® as illustrated in Figure 9.

The parameters of the whole system in the plant can be predicted easily by comparing the data output (position of platform in z-axis) acquired through real experiment with the data output acquired through simulation using parameters obtained initially. The parameters were then adjusted iteratively by trial and error method until both are analogous with each other. Figure 10 is an example of comparisons between data output (position of platform in z-axis) using initial and modified parameters. The bold dash lines are results from simulation while the solid lines are data obtained from the real system. Comparisons were made by utilizing random PID controller gains and input values. The parameters used in simulations were then adjusted to give output that performs closer to the real system or plant.

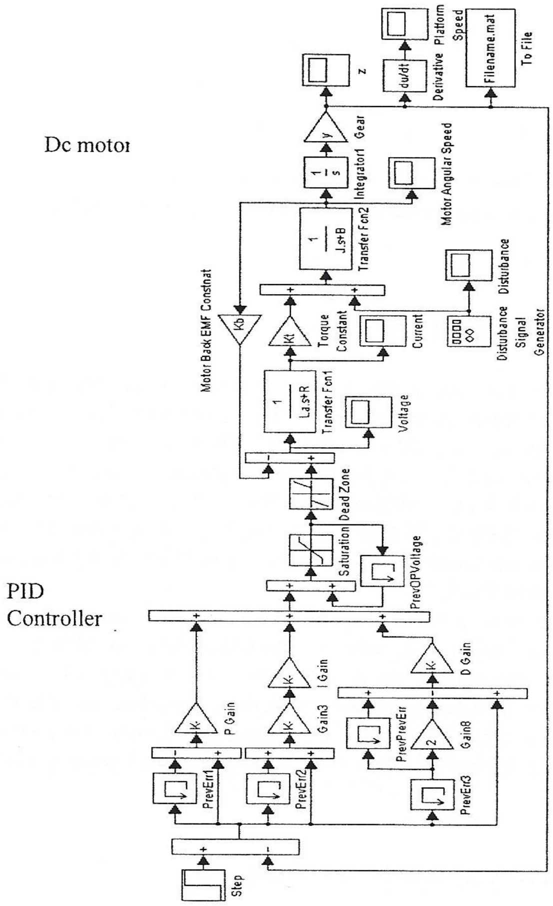

Figure 9: Developed PID Controller blocks using memory blocks with Saturation, Dead Zone and blocks of dc motor

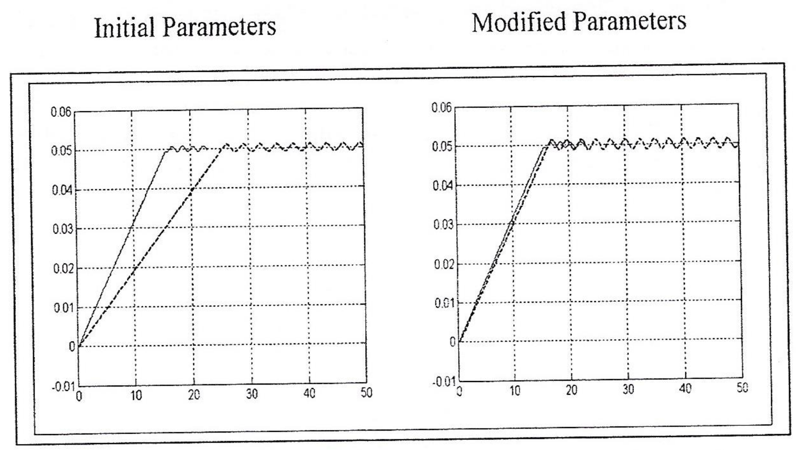

Figure 10: Comparison made with $K_p = 1000$, $K_i = 500000$ and $K_d = 0$ with $0.05m$ input

9.0 TUNING OF PID CONTROLLER

With the aid of simulation, the controller was tuned to obtain the initial or first estimation of PID controller gains. Based on this estimation, the controller was then fine tuned until the tuning goal was achieved. There are several proven tuning approaches or methods such as Ziegler-Nichols Approach, Atkinson Approach, F.G. Shinskey Approach, Decay Method, Reaction Curve Test Method and Bang-bang Oscillation Test Method [7] that can be used in this design. The designed PID controller was tuned based on the proven Ziegler-Nichols Approach since it was the most practical method.

The aim of tuning is to achieve a system that can produce zero or minimum overshoot with no oscillation. The antenna positioner must be able to go to the desired position at maximum speed and slow down gradually only when approaching the target. The last criterion is that the controlled variable must have minimum steady state error lower than the sensor resolution. This steady state error is caused by the limitation of the hardware that cannot support the reading finer than it can read.

10.0 CALIBRATION AND CORRECTION

Calibration is an important part in the design of a new instrument to assess its accuracy and thus allowing the comparison of its performance against the standard specifications [8]. Calibration data also can be used as a purpose of error compensation and also as diagnosis aids for machine maintenance

According to ISO 10012-1:1992(E) [9], correction is defined as the value which is added algebraically to the uncorrected result of a measurement to compensate for an assumed systematic error. Considerable research has been performed according to Marco A. Meggilaro [10] in robot calibration. The position accuracy can be improved using compensation methods that essentially identify a more accurate functional relationship between the sensor readings and the workspace position based on experimental calibration measurements. The correction is equal to the assumed systematic error but of opposite sign. In this design the corrections were done by focusing on the software optimization as the hardware is hardly to be modified and the cost of hardware modification is extremely high. According to K. K. Tan [11], compensation in the hardware via mechanical correction, however, inevitably increases the complexity of the physical machine. Furthermore, mechanical correction is not effective due to mechanical wear and tear. They have to be serviced and replaced regularly and these involve higher cost. Software compensation are widely use because it is easier and cheaper [12].

The result of correction apparently shows that the compensated results are greatly improved over uncompensated results. The ratio of the uncompensated error to the worst compensated error is approximately 5 times ($500\mu m$ vs. $100\mu m$).

The standard deviation of the results for both the corrected positions and set point predetermined randomly shows that both the data has no large discrepancy. The largest discrepancy with standard deviation $\sigma = 8.94\mu m$ is even smaller than the resolution of the designed system. This data with very small standard deviation explains that the designed instrument is very precise where all independent test results (controlled variable with same set point) are other. Hence a very precise antenna positioner was designed.

In order to calculate total error and uncertainty of the instrument, statistical approach is employed. This method of estimating uncertainty, although simple, is very pessimistic in its approach. The statistical approach employed is through normal distribution to calculate the error. The error calculated via normal distribution is called *Three Sigma Error*. The errors are calculated by assuming that a measurement whose deviation from the set point value, either positively or negatively, is greater than 3σ will occur only 1 in 370 times; or 369/370 (99.73%) of the time the error of a single measurement in the series will fall within $\pm 3\sigma$ [13]. The result indicates that the maximum or worse error that may occur in the corrected position is $\pm 50\mu m$ or approximately 29*ppm*. While the worst error that exists in the instrument with random input is $\approx \pm 300\mu m$ or approximately 176*ppm*. Thus, the instrument can be utilized in two ways.

11.0 CONCLUSION

An instrument with high precision performance was designed to be used as linear z-traverse antenna positioner. It was designed in the user friendly way to be operated in several different modes. All the procedures of design and developing a positioner both theoretically and practically were acquired.

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