DESIGN OF PRECISION LINEAR Z-TRANSVERSE ANTENNA POSITIONER

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A DESIGN OF PRECISION LINEAR Z-TRANSVERSE ANTENNA POSITIONER

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DEDICATION

To my dearest and loving parents,
brother and sister
for their unending love, encouragement,
sacrifice, and moral support

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ABSTRACT

An antenna positioner is essential device in avionics as a testing instrument. It must be able to move the antenna under test (AUT) to the required position precisely and accurately. This research focuses on the design of precision linear z-traverse antenna positioner. It comprises designs of mechanical, electrical and control system. Besides, knowledge on software design is also of paramount important because the designed instrument run by own developed control algorithm. It is a positioner powered by a DC motor as an actuator which is equipped by a user friendly graphical user interface (GUI) written uniquely featured with several distinct and systematic operating modes and flexible data display. PID (Proportional, Integral and Derivative) controller embedded in GUI is also capable to move AUT to the target in shortest time with no or minimum overshoot and steady state error. In this research, PID controller was tuned to suit the application with the aid of MATLAB® simulation. The system was then calibrated. Based on calibrated data, it was then optimized to yield more accurate result by mean of correction through software compensation. The result was then analyzed and discussed. A very precise instrument with standard deviation $\sigma = 8.94\mu m$ was successfully designed. It was designed to be used in two ways with accuracy of approximately $\pm 50\mu m$ or $29ppm$ for high accuracy usage and approximately $\pm 300\mu m$ or $176ppm$ for lower accuracy usage. As a consequence, procedures of design and developing a positioner both theoretically and practically were acquired.

ABSTRAK

Penentu lokasi antena merupakan satu alat yang penting dalam avionik sebagai instrumen kajian. Penentu lokasi antena mesti dapat membawa antena yang dikaji ke tempat yang diperlukan dengan jitu dan tepat. Penyelidikan ini memfokuskan segala usaha ke dalam merekacipta sebuah penentu lokasi antena jitu yang bergerak pada paksi z yang merangkumi rekacipta dari segi mekanikal, elektrikal dan sistem kawalan. Pengetahuan dalam perisian juga tidak kurang dari segi kepentingannya kerana rekacipta intrumen ini memerlukan aturcara untuk tujuan kawalan yang dibangunkan sendiri. Instrumen ini dikuasakan dengan motor arus terus. Sistem ini juga dilengkapi dengan *graphical user interface* (GUI) yang ditulis dengan unik di mana alat ini dapat berfungsi dalam beberapa jenis mode operasi yang sistematik dan juga paparan data yang mudah ubah dalam pelbagai keadaan. Pengawal PID (*Proportional*, *Integral and Derivative*) yang ada dalam perisian juga dapat memandukan AUT ke sasaran dalam masa yang tersingkat tanpa atau dengan minimum lanjakan puncak dan ralat keadaan mantap. Dalam penyelidikan ini, pengawal PID dilaras khas untuk memenuhi applikasi yang selaras dengan rekaan sistem. Simulasi menggunakan MATLAB® diperlukan dalam memudahkan process mencari nilai-nilai PID yang sesuai. Sistem kemudiannya ditentukur. Berdasarkan data yang didapati dari tentukur, sistem dioptimakan untuk menghasilkan keputusan yang lebih tepat dengan menggunakan pampasan melalui perisian. Keputusan yang didapati kemudiannya dianalisa dan dibincangkan. Instrumen yang amat jitu dengan sisihan piawai $\sigma = 8.94\mu m$ telah direkacipta. Intrumen ini boleh digunakan dalam dua cara dengan ketepatan alat $\pm 50\mu m$ atau 29*ppm* untuk kegunaan dengan ketepatan yang tinggi dan ketepatan $\approx \pm 300\mu m$ atau 176*ppm* untuk kegunaan dengan ketepatan yang lebih rendah. Dengan itu, langkah-langkah merekacipta dan membangunkan penentu lokasi antena secara teori dan praktik diperolehi.

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LIST OF SYMBOLS

β	-	Common Emitter Current Gain
$\ddot{x}$	-	Acceleration in x-axis
x	-	Displacement
P	-	Force Acts Up to the Direction to Move the Load in Lead Screw
ψ	-	Helix Angle
λ	-	Lead Angle
Φ	-	Magnetic Flux
m_l	-	Mass of Load
d_m	-	Mean Diameter
μF	-	Micro Farad
J_l	-	Moment Inertia of Screw Driven Load
N_g	-	Number of Teeth of each Gear
Ω	-	Ohm
H_o	-	Peak to Peak Amplitude
$\ddot{\theta}$	-	Rotational acceleration
a	-	Acceleration
A	-	Ampere
B	-	Magnetic Flux Density
B	-	Viscous Friction Coefficient
C	-	Capacitance
C	-	Coulomb Friction
$d1$, $d2$	-	Result of Calculation Representing Distance in Algorithm
dPre	-	Initial Absolute Position in Algorithm
e	-	Error
F	-	Axial Forces Acting upon the Normal Thread Area

I	-	Current
j	-	Counter in Algorithm
K_b	-	Motor Back Emf (Electromotive Force) Constant
K_c	-	Critical or Ultimate Gain
K_d	-	Derivative Control Gain
K_p	-	Propotional Control Gain
K_T	-	Torque Constant
l	-	Lead or Distance Moved by Nut when Lead Screw is Turned a Revolution
m	-	Meter
m, p	-	Sequences of Gray Code in Encoder in Algorithm
N	-	Normal Force in Lead Screw
n	-	Turn of Winding
n	-	Number of Revolution
p	-	Pitch
ppm	-	part per million
q	-	Number of Threads
r	-	Radius
R	-	Radius of Rotating Parts
R	-	Resistance
s	-	Second
t	-	Time
T	-	Torque
T_i	-	Integral Control Gain (Often Seen as $1/K_i$)
T_q	-	Period of Decaying Oscillation
T_u	-	Period of Oscillations
u	-	Output Signal from Computer
V	-	Voltage
W	-	Watt
z	-	Displacement in z-axis
ω	-	Angular Velocity

LIST OF ABBREVIATIONS

ADC	-	Analog to digital converter
AUT	-	Antenna under test
B1-B12	-	Bit 1 to Bit 12
BS	-	British standard
DAC	-	Digital to analog converter
DC	-	Direct current
DPDT	-	Double pole double throw
GUI	-	Graphical user interface
ISO	-	International Standards Organization
MSB	-	Most significant bit
LSB	-	Less significant bit
OP	-	Manual Step Output
ppm	-	part per million
PID	-	Proportional, integral and derivative
PV	-	Process Variable (Feedback from Sensor)
PWM	-	Pulse width modulation
QAD	-	Quarter Amplitude Damping
RF	-	Radio frequency
RFI	-	Radio frequency interference
SP	-	Set Point
TTL	-	Transistor-transistor logic

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CHAPTER 1

INTRODUCTION

There are three main elements in avionics. They are electrical system, control system and navigation system including the design of antenna propagation and microwave. In order to obtain the characteristic of an antenna, high precision equipment (positioner) is needed to move the antenna to the specified and predefined location. This is essential in testing the antenna for antenna gain radiation pattern measurement. Precision positioning instruments are getting more important due to increasingly in demand in the application of high-end research and high-tech industry. There are two types of positioner required namely; rotational (azimuth) and linear positioner. This project concentrates on the linear z-transverse antenna positioner. Research is currently conducted on producing an accurate, portable, user friendly, and low cost linear positioner that could carry heavy load.

1.1 Overview

Developing a linear z-transverse antenna positioner require an integration of knowledge in mechanical system, electrical system, computer science and finally control system design. The purpose of this project is to design a suitable servomechanism. Servomechanism describes a closed-loop electromechanical control system that directs the accurate movement of a physical object such as in linear positioner. Normally, the output position is controlled. In this case, the controlled variable is the position of the antenna. The antenna will transverse in z-direction and it is rotated by a DC motor governed by the controller. The controller will be located some distance away and the user could control direction of the movement by using preset modes to relocate the antenna to a specific position (Christopher T. Kilian, 2001).

Initially, a mechanical skeleton that can withstand the load of antenna and move the antenna to the required location has to be designed. From the mechanical system, an electrical system and control circuit are added. The hardware needs proper interfacing with software to achieve the purpose of controlling. All signals and commands from the user are interfaced through computer software (controller) that is designed in the form of graphical user interface (GUI). GUI is required to set the parameters of the control algorithm. GUI provides easy access to the necessary parameters and programming function. Bridging the software and the mechanical/electrical systems is through analog to digital or digital to analog converters (ADC/DAC) and data acquisition interface card. Software or controller will then need to be set appropriately by control algorithms to overcome problems regarding to control system. In other word, fine tuning will be done after the general system such as mechanical system, electrical system and computer system has shown to be working harmonically but does not possess the necessary accuracy.

The benefits of this project will be the localization of the knowledge in Malaysia in the area of antenna measurement technique and associated equipment.

1.2 Thesis Objectives

This thesis has identified several objectives that must be achieved as to fulfill the requirements of the research. They are:

i. To acquire the knowledge on antenna measurement instruments from theoretical application.

ii. To localize the knowledge on antenna measurement techniques and product in Malaysia.

iii. To study the precision methods to measure linear movement with accuracy equal or better than $50 ppm$ over full scale and to apply the optimum method to an antenna positioner design.

iv. To develop mechanical, electrical and control system.

   a. To control the movement and the positioner by interfacing the mechanical and electrical system with computer.
   b. To fabricate and test the developed prototype system.
   c. Analyze to optimize and to achieve the desired controller settings to solve the problems such as overshoots, long settling times, unwanted oscillations and steady state error.

1.3 Antenna Positioner

Antenna Positioner is an instrument that is used in measurement and position adjustment applications. The main function of the instrument is to locate the RF (radio frequency) probe to the desired position. The design aims for this instrument are accuracy, simplicity, maintainability, portability, user friendly, low manufacturing/fabrication cost and safety. They are the basic guidance in the process of designing. Several instrumentation characteristics must be specified and considered. They are payload capacity and maneuverability, torque, rotary joints, ease of installation & alignment, and control system. All of which must be compatible with each others.

Positioner must also provide reacting against the payload and as a reference of the payload position and orientation to the coordinate system. In this thesis, the payload here means antenna under test (AUT). Most of the existing positioners use single mechanical skeleton for both purposes. They are optimized so that the instrument can act as reaction and measurement skeleton.

The antenna has its own weight and it is also subjected to gravity, payload acceleration, aerodynamics and other forces. Therefore, the mechanical structure of positioner will provide reaction for the antenna. While the measurement system measure the payload position relative to a reference coordinate system (Dan Slater, 1991).

The effort of calibration helped to source out the error that could be corrected. Study and analysis on the result of calibration had been made. To optimize the accuracy and precision of the instrument, corrections or compensation was carried out based on initial calibration data. Due to inevitable uncertainties, the correction manages to improve the accuracy to $\pm 50\mu m$ or approximately 29*ppm* for high accuracy usage and $\approx \pm 300\mu m$ or approximately 176*ppm* for lower accuracy usage. Besides, the aim to design and develop a precise instrument was achieved since the instrument shown to have the standard deviation, $\sigma = 8.94\mu m$ where it is only approximately 1/3 the resolution of designed instrument.

7.2 Recommendations and Future Research for Improvement

The hardware should be further upgraded by using non-contacting sensor to avoid uncertainties that are cause by the lacking in hardware that induce nonlinear behavior such as hysteresis, backlash and dead zone in the system. By using non-contacting sensor, errors due to non-ideal geometry of the hardware as a consequence of bad machining tolerances can be ignored.

The hardware also needed to be upgraded by using more precise components to avoid unwanted misalignment, vibration and noise while the instrument is working.

In order to obtain better accuracy and precision, compensation or correction can be made more frequent by dividing full travel range into more partitions. Nonlinear interpolation may be used as well to improve the accuracy instead of using linear interpolation. As a consequence, the partitions will be able to transverse in their unique control algorithm to yield better result. Besides, it is also possible to achieve even better results by performing the compensation for a second time on the first compensation. By performing these enhance procedures, it should guarantees better accuracy.

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