Design and Realisation of Antenna Control Servo System using Direct Drive Motors

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***ABSTRACT:-* Antenna Control Servo System (ACSS) of Doppler Weather Radar (DWR) plays a Vital Role in Antenna Positioning Mechanism to Receive the transmitted signal from the target with less or no deviations from the desired position in different modes of DWR operation as per the selected scan strategy. In order to overcome the Backlash effect occurred in Geared system, Direct Drive technology is implemented. This paper describes the design of direct drive motor as per the torque requirements imposed by the antenna structure. Use of direct drive motors avoids gear box, thereby avoiding the Backlash Effect. Modeling of ACSS and Tuning of the control loops is carried out by using MATLAB/SIMULINK software. Servo integrated checks are carried out by using S748 Servo Amplifier through PC based Drive GUI Software.**

Key words:- ACSS, DWR, Backlash Effect, Direct Drive, S748 Servo Amplifier, Drive GUI

I. INTRODUCTION

Doppler Weather Radar (DWR) is a long-range weather radar surveillance system that measures the rainfall intensity during severe weather conditions and provides the information about target position and its velocity. Doppler weather radar can be operated in various frequency bands such as W, K, X, C, S and L.

The Proposed antenna control servo system design is implemented on the X-band Frequency range.

The Antenna Position control servo system generates the drive for Azimuth and Elevation motors for the movement of the antenna in Azimuth and Elevation axes. As per the selected scan strategy, the instantaneous reference angles for both Azimuth and Elevation are computed and the antenna is positioned accordingly. The angle data in azimuth and elevation axes is obtained from absolute encoders, which is subtracted from reference data to generate the position error. Antenna control servo system is normally controlled by Radar Controller (RC), where the radar operation is selected. ACSS can be operated in both Local and Remote mode of operation.

The Servo Controller (motion controller) is a processor based system with necessary front end GUI and associated software to configure the servo subsystem for different modes of operations.

Limit switches are provided for the safety of the Antenna and interface cables.

The antenna is driven in azimuth and elevation axes through individual servomotors used in both azimuth and elevation channels. The servomotors in Azimuth and Elevation channels will be connected to the respective servo amplifiers for both drivelines.

The block diagram of the proposed system is as shown in the figure 1.1.

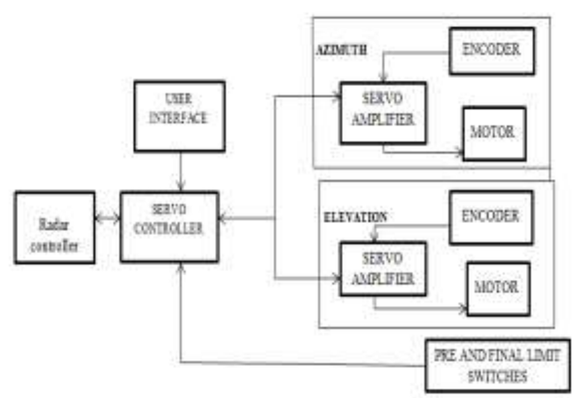

Figure 1.1: Block Diagram of the proposed system

In a servo system, feedback information - motor position, motor velocity and motor current are sensed and used in servo drive amplifier for proper operation of the motor. The servo amplifier S748 analyses the feedback, makes compensation as needed, and generates drive to motor for required antenna movement.

A. EXISTING SYSTEM

In existing system the antenna control servo system makes use of gearbox for the power transmission from motor to the load shaft.

The disadvantages of gear drive system are:

- Produces Backlash Effect
- At high speed noise and vibration occurs
- High Maintenance and cost is required

B. PROPOSED SYSTEM

The proposed system replaces the use of Gearbox by implementing the direct drive technology which can be placed directly on the load shaft without any power transmission devices. The antenna mount for the proposed system using direct drive motor is as shown in the Figure 1.2.

Figure 1.2: Antenna Mount of the Proposed System

II. SYSTEM SPECIFICATIONS

The major system specifications of the proposed system are as follows:

Type of Mount	Elevation over Azimuth
Azimuth Range	0 to 360 deg continuous
Elevation Range	-2 to 92 deg
Azimuth Scan Rate	Up to 36 deg/sec
Elevation Scan Rate	Up to 12 deg/sec
Acceleration in AZ and EL axis	20 deg/sec^2
Angular Data Resolution	0.01º or better
Position Accuracy	0.1° or better

Table 1: System Specifications

III. SYSTEM DESIGN

Selection and sizing of the motor requires the inertia and torque estimates of the antenna structure. The selected motor must be able to safely drive the mechanical set up by providing sufficient torque and velocity.

Load inertia for all the components can be calculated using the equation as follow:

$$J_L = \text{mass} \times distance^2 \quad \text{kg-}m^2 \qquad (1)$$

The amount of torque needed by the load can be calculated by the inertia reflected from the mechanical setup to the motor and the acceleration at the motor shaft.

The equation to calculate the load torque is as given below:

$$T_L = \text{Load Inertia } (J_L) * \text{ Acceleration} \qquad (2)$$

The continuous torque requirement needed to select the motor involves the calculation of inertia of all the moving components, inertia reflected to motor, drive inertia, acceleration at motor shaft, acceleration torque at motor shaft, wind torque required to sustain the heavy winds, friction torque and unbalance torque imposed by the mechanical setup. The continuous torque requirement needed by the mechanical setup is found to be 500 N-m for both azimuth and elevation axis.

In order to provide the continuous torque requirement of 500 Nm for both azimuth and elevation axis direct drive servo torque motor TMB03600-150-3XBN from ETEL motion technologies is selected and Servo Star S748 Servo Amplifier of S700 series from Kollmorgen is selected to provide the continuous current rating of 48A to the motor.

The general motor selection and sizing process can be summarized in the form of Flow chart as shown in Figure 3.1.

A. CONTROL SYSTEM DESIGN

Control System Design of the DWR consists of Calculation and Tuning of Current Loop, Rate Loop and Position Loop for both Azimuth and Elevation Axis such that the Servo Control System can achieve optimum performance. Control loops design requires the calculation of Motor transfer function by deriving the electric servo motor equations and time constants [3].

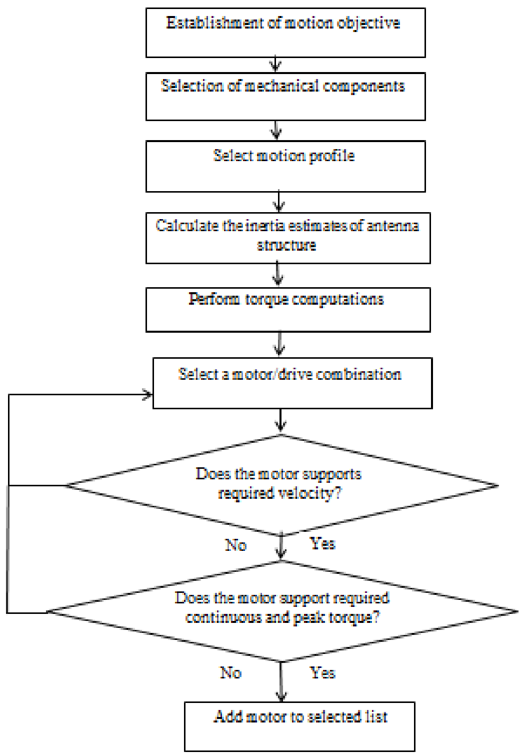

Figure 3.1: Motor Selection Flow chart

The transfer function obtained for the selected motor is as follows:

$$\mathbf{TF} = \frac{Kt}{(Js+B)(sL+R)+KtKe} \qquad \textbf{(3)}$$

The standard Trapezoidal Curve theory is used by servo controller to control the Position loop of the system.

The control plant diagram with the position, velocity and current loops required to tune the system performance is as shown in the figure 3.2.

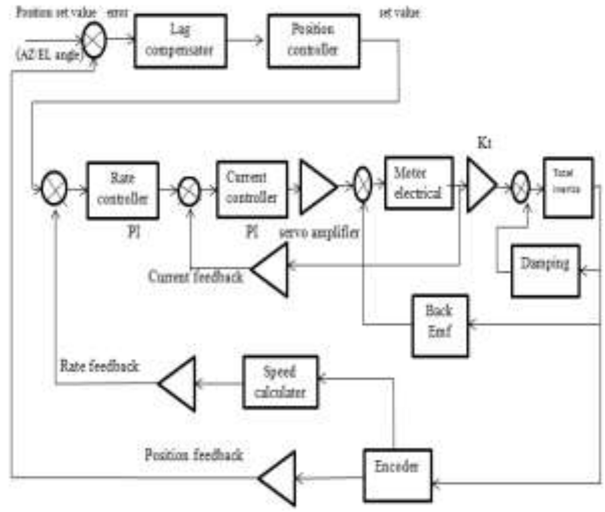

Figure 3.2: Control Plant Diagram

IV. METHODOLOGY

The operational sequence required to drive the antenna in azimuth and elevation axis in desired position is as discussed as follows:

1. When the antenna is in a fixed position, the motor is stationary. The current feedback and the velocity feedback from the motor are both zero. The encoder feedback will have a specific value. (i.e azimuth angle and elevation angle). When a set point for the antenna position is changed, due to the controller action, the power amplifier received a signal. The power amplifier (which also acts as a PI controller) amplifies the signal which is then fed to the servo motor. Once the motor starts running, the current sensor in the feedback loop gives the feedback to the current. The current controller then adjusts the gains and feeds the signal to the power amplifier where it is amplified and fed to the servo motor to achieve the required torque characteristics.

2. Resolver is used as the feedback component in the velocity feedback loop. The resolver measures the speed of the servo motor (RPM) and by its working mechanism, converts it into a voltage signal which is fed to the velocity controller. The velocity controller kicks in and adjusts the gain parameters according to the tuning and the requirements of the current controller

3. Encoder is used as the feedback component in the position control loop. The encoder is mounted above the antenna and it measures the antenna azimuth and elevation angle, which is given as the feedback signal (current position of antenna) to the position controller.

The position controller also receives as the input which is the set point. Whenever the set point and the current position differ, an error signal is generated by the position controller.

The control loops operation can also be analyzed in ideal software environment by converting the control plant diagram of the proposed system into its mathematical form as shown in the figure 4.1.

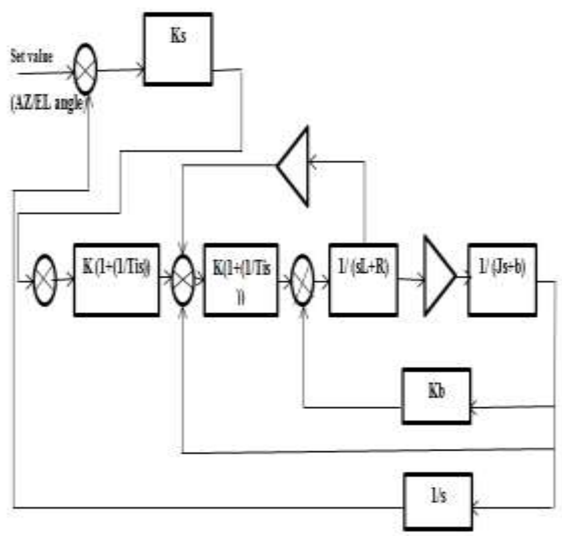

Figure 4.1: Mathematical representation of the control plant diagram

The control approach as discussed in the previous topics can be employed by modeling the proposed system in MATLAB/SIMULINK software in order to tune the control parameters to achieve the optimum system response.

V. SIMULATION

The tuning of the control loops can be done by various ways and various methods of tuning can be done in order to obtain the desired response of the system. In order to implement these tuning methods the entire system is represented with the transfer function and must be simulated in an ideal environment. Here, PID tuning method is implemented to obtain the desired system response within the specified system requirements.

MATLAB offers an ideal environment in order to simulate and tune the Antenna Control System. It consists of an inbuilt section that allows us to recreate the control system ideally known as Simulink. The entire representation of the Antenna Control System in Simulink is as shown in figure 5.1.

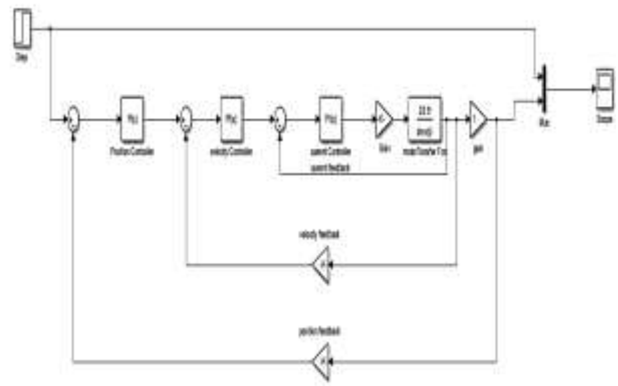

Figure 5.1: Simulink Model of the ACSS

System requirements are as follows:
Bandwidth of rate loop< 6Hz
Rise time< 1 ms
Overshoot< 5%
Settling time< 5 ms

Therefore controller should be designed and tuned in such a way that the system response meets the above specified requirements.

VI. RESULTS

The design and simulation results for the control loops of antenna control servo system are exhibited in the following figures respectively. Figure 6.1 shows the tuned response for the position loop controller. Figure 6.2 and 6.3 shows the tuned response for velocity loop and current loop controller respectively. Figure 6.4 represents the step response obtained for the tuned Simulink model. Bode plot for the Simulink model is as shown in the figure 6.5. The rise time, settling time and overshoot from the obtained step response are found to be 0.637 ms, 4 ms & 3% respectively. From the bode plot the bandwidth of the rate loop is found to be 3.5 Hz. All the results are found to be satisfactory and are within the required specifications.

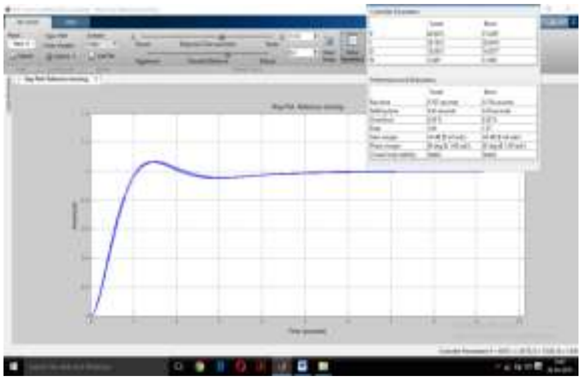

Figure 6.1: Tuned response of position loop controller

Figure 6.2: Tuned response for velocity loop controller

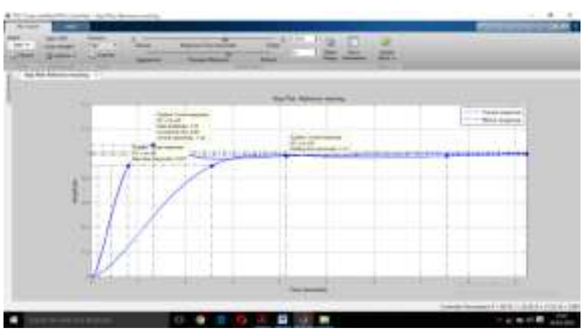

Figure 6.3: Tuned response of current loop controller

Figure 6.4: Step Response of the Simulated Model

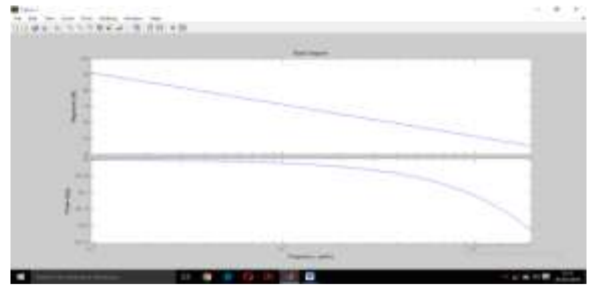

Figure 6.5: Bode Plot of the Simulated Model

VII. HARDWARE REALISATION

In order to monitor the motor current drawn at different speed, acceleration achieved by the antenna and rate loop tests, Servo integrated checks are carried out by connecting the servo amplifier with RS232 cable to the serial port of Laptop/PC having Drive GUI software. Figure 7.1 shows the motor current drawn at 1 RPM speed. The continuous current rating is 17 A and the current obtained is 1.8A. Hence, the results found are satisfactory. Figure 7.2 shows the speed response on oscilloscope of servo amplifier and the acceleration achieved is found to be 19.14 deg/sec^2 at 2 RPM Speed. The results found are satisfactory as the set maximum acceleration is 20 deg/sec^2. Figure 7.3 shows the velocity response on oscilloscope of servo amplifier at 1 RPM and the rise time and bandwidth are found to be 0.537 ms & 3.5 Hz respectively.

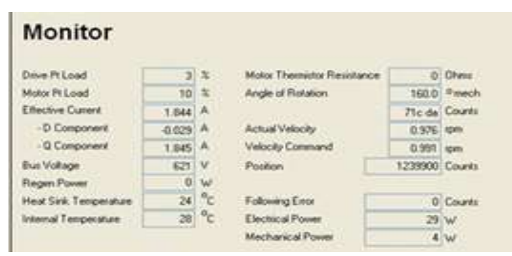

Figure 7.1: Motor Current drawn at 1 RPM Speed

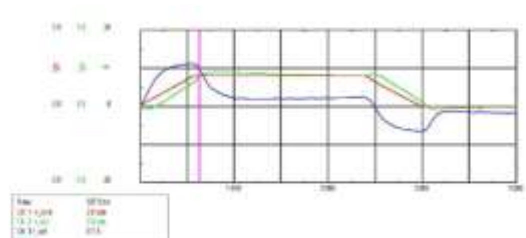

Figure 7.2: Speed Response on oscilloscope of servo amplifier at 2 RPM speed

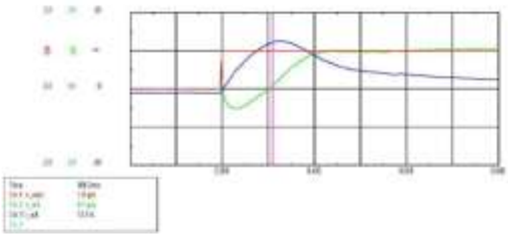

Figure 7.3: Velocity response on oscilloscope at 1 RPM speed

VIII. CONCLUSION

In order to achieve the precision in the antenna positioning, the antenna control servo system is designed to control the antenna movement in Azimuth and Elevation axis. The limitations of geared system can overcome by using the direct drive motor. Direct drive motor improves the performance of the system with increased efficiency, reduced noise, longer life time, high torque at lower speed, fast and precise positioning and drive stiffness. The integrated antenna and servo checks are carried out are found satisfactory as per the required specifications.

IX. REFERENCES

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