Research Inventy: International Journal of Engineering And Science
Vol.4, Issue 5 (May 2014), PP 12-15
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

A New Approach to analysis of t-domain and f-domain in A Nose-Wheel Steering of Medium-Haul Air-Craft

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ABSTRACT - *Electromechanical nose-wheel steering systems give the Medium-haul air-crafts the needed maneuverability and durability. These air-crafts are of intermediate size. They must be able to utilize small air-fields, having little or no service and maintenance facilities. During take-off, the nose-wheel steering keeps proper heading. Feedback from the nose-wheel heading is compared with the pilot command to generate the error signal. This signal is amplified and applied to a magnetic particle clutch, which activates the rotation of the wheel-heading. The paper deals with nose-wheel steering of Medium haul aircraft. The design specifications are conflicting with each other. To keep the steady state error at a low value the forward path gain must be high. At the required value of the gain, the system becomes unstable. Addition of rate feedback makes the system stable but it fails to satisfy the transient requirement. The overshoot remains at a high value even if the coefficient of rate feedback is varied over a wide range. The required t-domain performance could be achieved by the addition of weighted acceleration feedback. The specifications could be fulfilled by suitably choosing the coefficients of rate and acceleration feedback. Starting from the block diagram, the mathematical model has been developed and the analytical treatment has been made by indigenously made computer program. The results have been verified by using MATLAB-tools.*

Keywords - *Nose-wheel, Medium-haul air-craft, Rate & acceleration feedback, Steady state error, Overshoot.*

I. INTRODUCTION

The present day aero planes vary widely in size and carrying capacity. The range is from ultra- light aircraft to carry a single man, who happens to be the pilot, to great jumbo jets capable of carrying several hundred people and several hundred tons of cargo. [15]-[16]. Airplane pilots reply. On a set of instruments in the cockpit to monitor airplane systems, to control the flight of the aircraft, and to navigate. Two classes of instruments are used: the systems instruments and the flight instruments [3]-[14]. Airplanes now employ satellite navigation systems and computers to navigate from any point on the globe to another without any help from the ground. The Global Positioning System (GPS), developed for the US military, is now used by many civilian pilots. It provides information on the position of the air-plane within the accuracy of a few meters. Such facilities are available in important air-stations in large cities e.g. at New York, Hithro etc.). But such modern facilities are not available at relatively unimportant air-stations (e.g. at Agartala) where Medium-haul air-crafts take off and land [4]. Electromechanical nose-wheel steering systems give the Medium-haul air-crafts the needed maneuverability and durability. These air-crafts are of intermediate size. They must be able to utilize small air-fields, having little or no service and maintenance facilities. The nose-wheel steering keeps proper heading during take-off and landing [1][2][14].

II. DESCRIPTION OF THE SYSTEM

The block diagram of the control system for nose-wheel steering of a Medium-haul aircraft is given in fig.1. Feedback from the nose-wheel heading is compared with the pilot command (desired heading) to generate the error signal. This signal is amplified and applied to a magnetic particle clutch, which activates the rotation of the wheel-heading [5][6][8]. Initially attempts were taken to design the system with proportional feedback. The gain was fixed up from the requirement of steady state accuracy. It made the system unstable. So rate feedback was added to stabilize the system. But the transient performance was poor, the overshoot was very high. In the next stage, acceleration feedback was added.

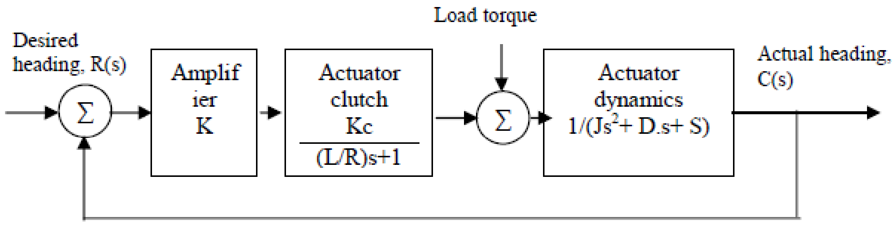

Fig1 Nose-wheel steering of Medium-haul air-craft

III. MATHEMATICAL DESCRIPTION

With reference to the block diagram, the following data have been collected: Actuator clutch gain, = 1; Moment of inertia, J = 1; Damping, D = 9; Rotational spring constant, S = 9; L/R ratio = 0.1. Based on these data we get the open loop transfer function as:

$$G(s) = \frac{C(s)}{R(s)} = \frac{K.K_C}{[(L/R)s+1](Js^2+Ds+S)} = \frac{K}{(0.1s+1)(s^2+9s+9)}; \; H(s)=1 \qquad 1$$

The closed loop transfer function is obtained from eqn. 1 is given below

$$M(s) = \frac{C(s)}{R(s)} = \frac{10K}{s^3+19s^2+99s+90} \qquad 2$$

The design specifications have to be fulfilled, if possible by varying the gain K.

IV. DESIGN SPECIFICATIONS

The design requirements are the following:

i. Phase margin of 60o.
ii. Gain margin > 25 db.
iii. Near critical damping, overshoot within 0.5 %
iv. The rise time < 0.75 sec. and the settling time < 1.5 sec.

We shall try to get the required solution using analytical procedure.
The general practice is to use Bode plot. But it gives inaccurate result as it is a graphical method, unless MATLAB-tools are used. So we shall use a special program for the solution. Noting that:

$$|G(j\omega)| = \frac{10K}{\sqrt{(\omega^2+100)[(-\omega^2+9)^2+81\omega^2]}} \qquad 3$$

$$\angle G(j\omega) = \tan^{-1}(\omega/10) - \tan^{-1}[9\omega/(9-\omega^2)] \qquad 4$$

The phase crossover is independent of the value of gain- it depends only on the value the angular frequency. We use Newton-Raphson method of convergence [16] to get the solution for the angular frequency at which the phase crossover occurs i.e. for which the phase of the loop gain is 180^o .It is found out that the solution converges at:

The gain crossover occurs at ω = 5.318 r/s; Corresponding amplifier gain, K=22.36, Phase margin = 40^o :
The phase crossover occurs at ω = 9.95 r/s; The gain margin =15.1 db.
The system is stable but the stability margins should be a little more for secured operation. Therefore a compensator should be added.

V. ANALYSIS USING MATLAB

MATLAB-tools have been used for perfection of the design. With reference to the root locus given in fig. 2 the forward path gain has been set at K=3.15. It gives almost critical damping. The time domain behavior of the system for this gain is given in fig.3 and the Bode plot in fig.4.

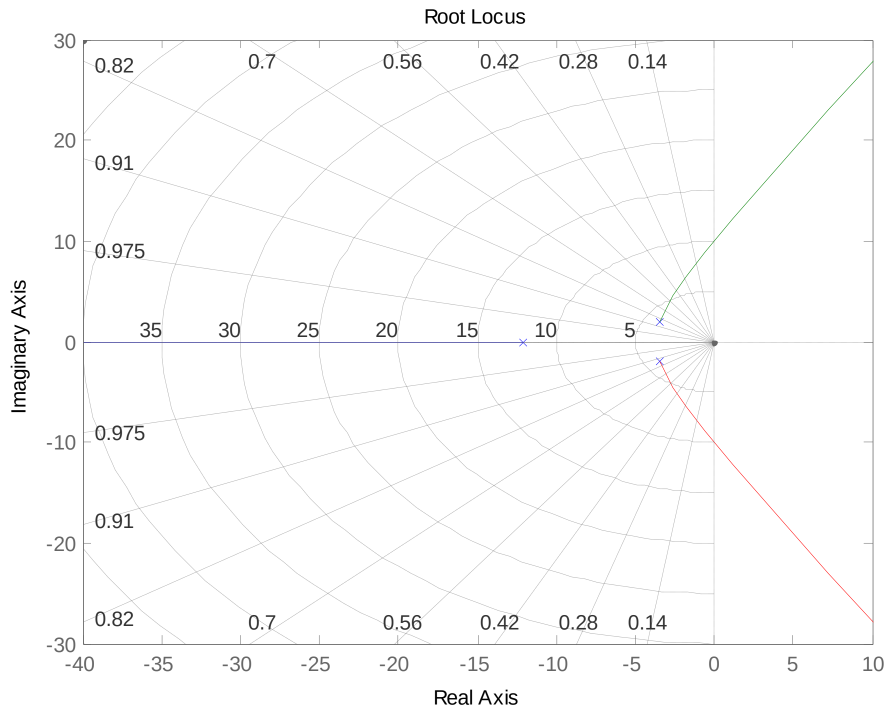

Fig.2 Root locus of nose wheel steering of Medium haul aircraft

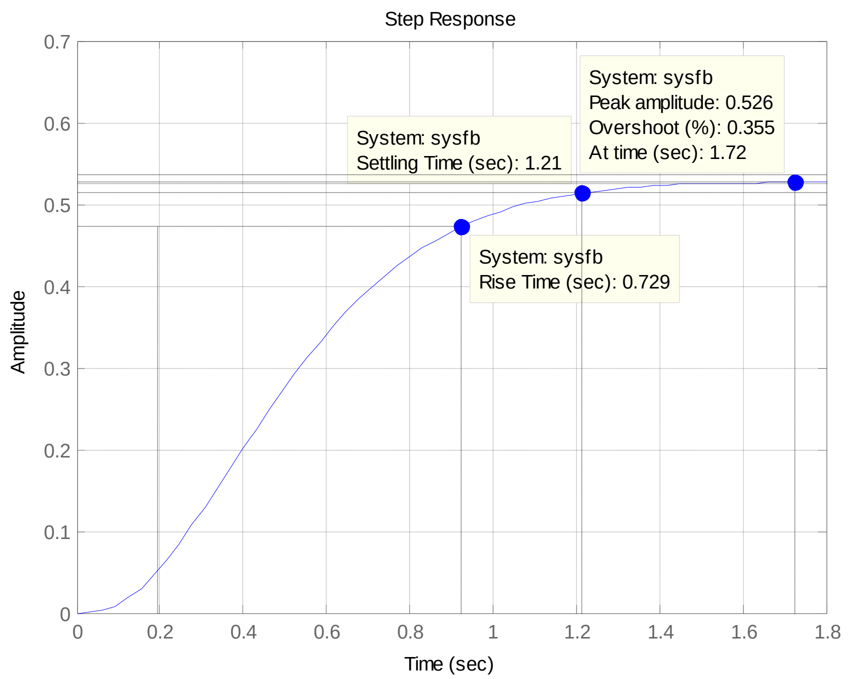

Fig 5.3 Time domain response of Nose Wheel aircraft for K=3.15

The t-domain analysis reveals the following: Rise time= 0.729 sec.; % overshoot= 0.365; Peak time = 1.72 sec; The settling time = 1.21 sec.

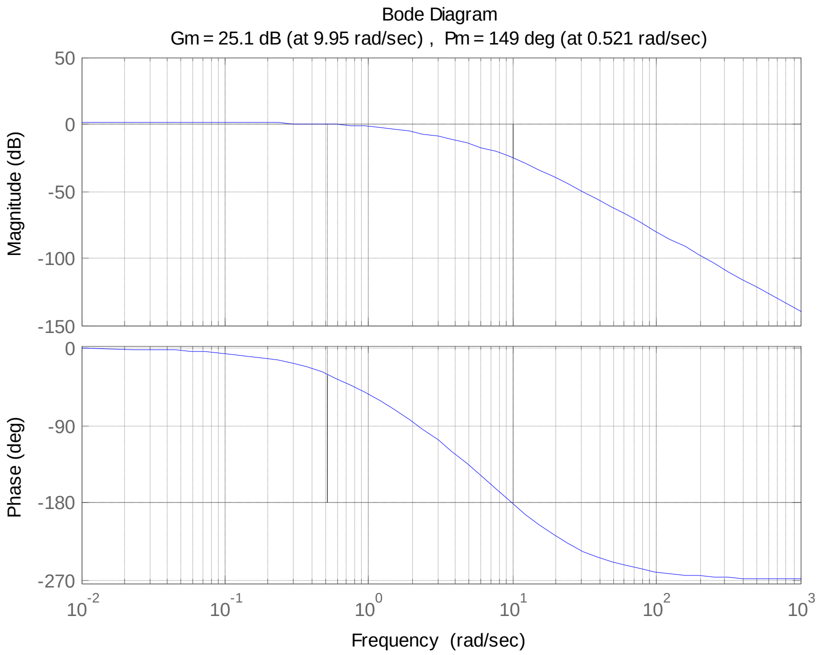

Fig .4 Bode plot Nose Wheel aircraft for K=3.15

From Bode plot, we get: Gain margin=25.1 db at 9.95 r/s and the phase margin = 149^o at 0.521 r/s. These margins are adequate for a robust design.

VI. CONCLUSION

The case-study has been made on nose-wheel steering of Medium-haul aircraft. Electromechanical nose-wheel steering systems give the Medium-haul air-crafts the needed maneuverability and durability. These air-crafts are of intermediate size. They utilize small air-fields, having little or no service and maintenance facilities. During take-off and landing, the nose-wheel steering maintains proper heading employing feedback control. Design for the steering system, has been made with reference to the root locus so that almost critical damping is obtained. Then the t-domain and f-domain performance have been found out using MATLAB-tools. The performance has been found to be satisfactory.

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