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Design of Compensator for Roll Control of Towing Air-Crafts

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Abstract: **It is a difficult task to make proper adjustment of towing vehicles, keeping the motion secured and predetermined. In older days the control was manual. Now-a-days automatic feedback control systems are used. The specifications are very stringent due to imposition of govt. and industrial rules. There are constraints on steady state accuracy, transient performance and stability margins. The requirements are contradictory. If the steady state accuracy is realized, the transient requirements and the stability margins cannot be maintained. It is difficult to fulfil the requirements by modifying the feedback or adding feed-forward. It is expedient to add a compensator in the forward or feedback path. In this paper, the design of a towing aircraft has been taken up. Its block diagram and transfer function are given. The gain has been fixed up to keep the steady state error within prescribed limits. The transient performance has been shaped and stability ensured by adding a lag compensator of chosen parameters.**

Keywords: **Towing Air-Craft, Forward Path Gain, Feedback Path, Transient Performance indices, frequency-domain analysis, and stability margins.**

Symbols:

$r(s), c(s)$	Actual roll angle/ command roll angle	T, α	Parameters of the lag compensator
K	Forward path gain	K_v	Velocity error constant

1. INTRODUCTION

Coupling two or more objects together so that they may be pulled by a power source is called towing. The towing power source may be a vehicle, vessel, animal, or human, the load may be anything that can be pulled. The load and the power source may be joined by a chain, rope or bar or other means to keep the objects together while moving. Towing may be as simple as a tractor pulling a tree stump. In the extreme it may be a heavy duty task requiring enormous tractive force. Standards imposed by authorities are now prevailing to ensure safety and interoperability of towing equipment. In the same way, aircraft may tow one-another. Gliders carrying troop and cargo are frequently towed behind powered aircraft – it remains a popular means of shifting a load [1,2,11]. At this stage, it has to be appreciated that towing needs close control. An automatic control system against given constraints must be incorporated with all towing equipment

2. GUIDANCE AND CONTROL

The towing source and the load must match with each other while in motion. The roll of the power source is to be sensed by internal gyroscopes and accelerometers, and corrections are to be made by automatic control systems employing feedback. The steady state accuracy or precision level is specified which fixes up the system gain. The transient performance is also specified.

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It may not be possible to realize the desired performance and to meet the design specifications with an uncompensated system. In such cases a suitable compensator has to be inserted in the forward path. The compensators may be of lag, lead or lag-lead type [3]. Authors like S. Sanyal, A.N. Sanyal, R. Basak have used various types of compensators for designing industrial devices to match the specifications [6,7,8,9,10]. Design and its optimization can be made after modelling the system [4]. The matching has to be made in respect of steady state accuracy, time domain and frequency-domain constraints. Not only matching the specifications but also system optimization remains the ultimate aim [5]. In this work, quasi-optimal values have been found out by cut-and-try method.

3. BLOCK DIAGRAM

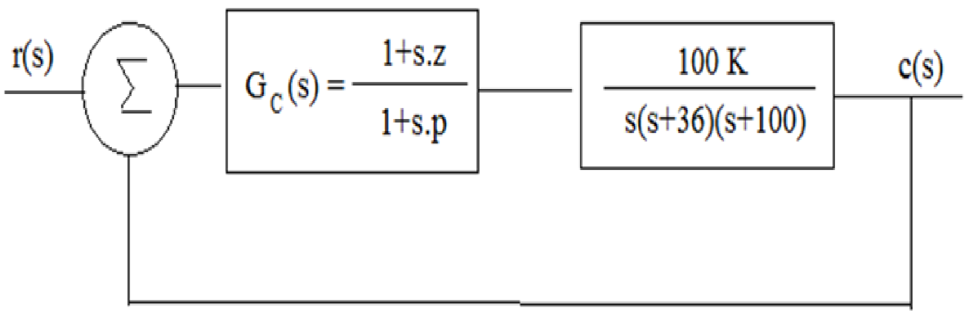

Fig. 1. Block diagram representation of the towing air-craft

It has been modelled as a linear continuous control system [4]. The dynamics of the aircraft has been given as a product of an integrator and two first order lags. The actuator gain has been given as 100, and the amplifier gain has to be adjusted to limit the steady state error. Unity feedback has been used. The design has been initially made without a compensator. As the specifications cannot be fulfilled without a compensator, a properly designed compensator has been inserted in the next stage [3].

4. SPECIFICATIONS

The following specifications are to be fulfilled.

The steady state error must be less than 1%

The transient overshoot is to be about 1%

The gain margin must be more than 20 db

The phase margin must be more than 60^o

5. MATHEMATICAL DESCRIPTION

With reference to the block diagram, the forward path and the feedback transfer functions (without the compensator) are given as [1,2,3]:

$$G(s) = \frac{r(s)}{c(s)} = \frac{100K}{s(s+36)(s+100)} \quad ; \quad H(s) = 1 \qquad (1)$$

The closed loop transfer function is given as:

$$M(s) = \frac{c(s)}{r(s)} = \frac{100K}{s^3 + 136s^2 + 3600s + 100K} \qquad (2)$$

K_p has been taken as 1 as it is a unity feedback system. From the closed loop transfer function, it is noted that the system is of 3^{rd}. order. The velocity error constant is given as:

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$$K_v = \frac{\omega}{error} = \frac{100}{1} = 100/\sec = \lim_{s\to 0} s\frac{100K}{s(s+36)(s+100)} = \frac{100K}{3600} \therefore K = 3600 \qquad (3)$$

Against this value of gain, the t-domain and f-domain performance has been evaluated using MATLAB [12,13,14] and are given in fig. 2 and fig. 3.

We note that the uncomopensated system fulfills the specification on steady state accuracy but fails to fulfill the criteria set up for transient performance and stability limits. So we must cascade a compensator of appropriate parameters.

In cascade compensation, the compensator is inserted in the forward path. The transfer function of the compensating network is designed to provide additional lag, lead or a combination of both. Accordingly they are designated as lag, lead or lag-lead compensator. All these networks are made up of two types of circuit elements viz. resistors and capacitors. A lag compensator has been used in this case for the following reasons [3]:

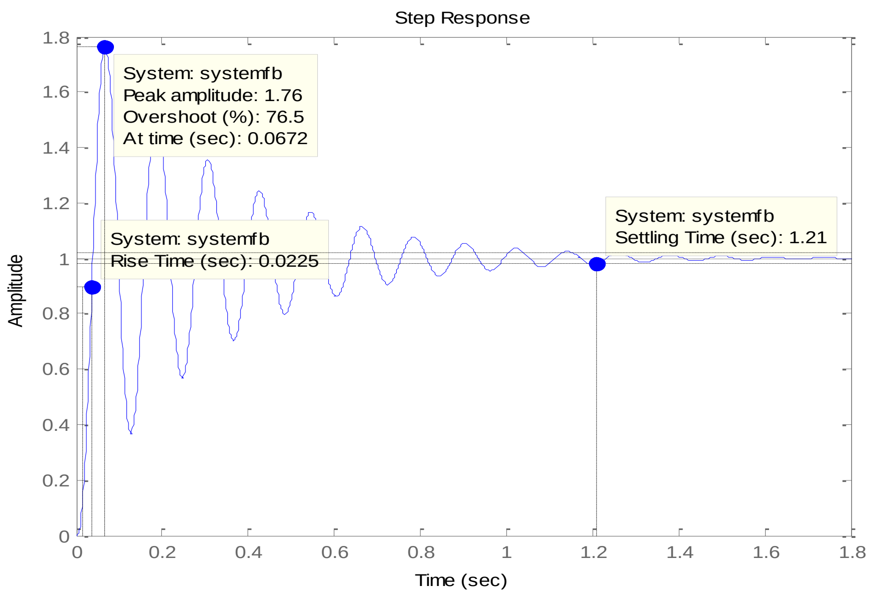

Fig. 2. Step response of the uncompensated system

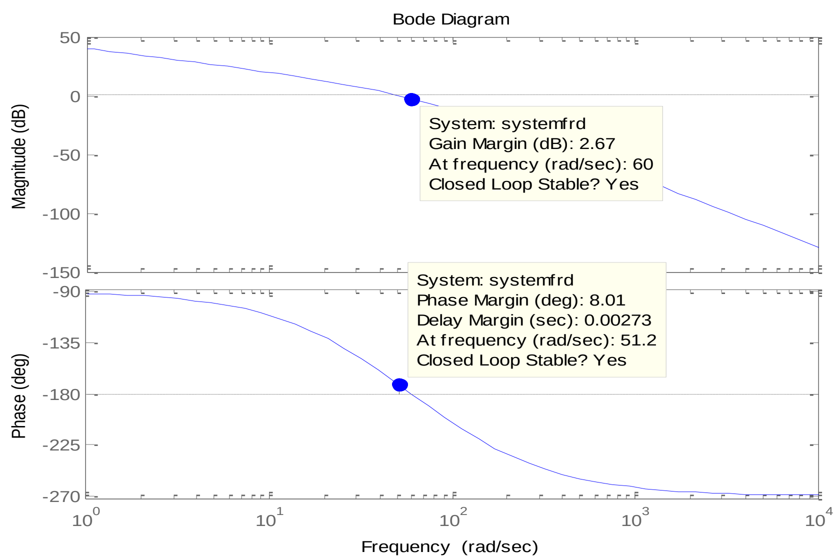

Fig. 3. Bode plot of the uncompensated system

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a) It is less expensive

b) Gives a smaller BW

c) The resulting system has less noise

d) The output response has less jitter

6. THE LAG NETWORK

The circuit configuration for the lag compensator is given [1,2] in fig. 4. In the phase lag network, the phase of the output lags the phase of the input. It has a simple pole and a zero in the left half of the s-plane, with the pole to the right of the zero.

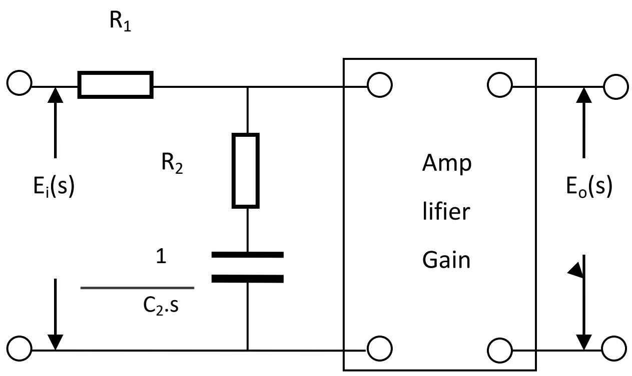

Fig.4 A lag compensator

The lag compensator attenuates high frequency noise in the control loop. It also increases the steady state error coefficients, thus reducing the error. The transfer function of the compensator is found to be:

$$G_c(s) = \frac{K_c(1+s\tau)}{1+\alpha s\tau}, \qquad (4)$$

Where, $\tau = R_2C_2$ & $\alpha = 1 + R_1/R_2$ (with ref. to fig. 4). The values of α & τ are to be adjusted to meet the design requirements. α is generally chosen between 3 & 10. We choose the following transfer function for the compensator:

$$G_c(s) = \frac{1(1+23s)}{1+230s}, \qquad (5)$$

The parameters have been chosen by cut and try method: $K_c = 1, \tau = 23, \alpha = 10$

The forward path transfer function inclusive of the lag compensator is given as:

$$G(s) = \frac{r(s)}{c(s)} = \frac{100K(1+23s)}{s(s+36)(s+100)(1+230s)} \qquad (6)$$

With this lag compensator in cascade, the t-domain and f-domain performances have been evaluated using MATLAB [12, 13, 14] and are given in fig. 5 and fig. 6.

Now, we find that all the design specifications have been fulfilled.

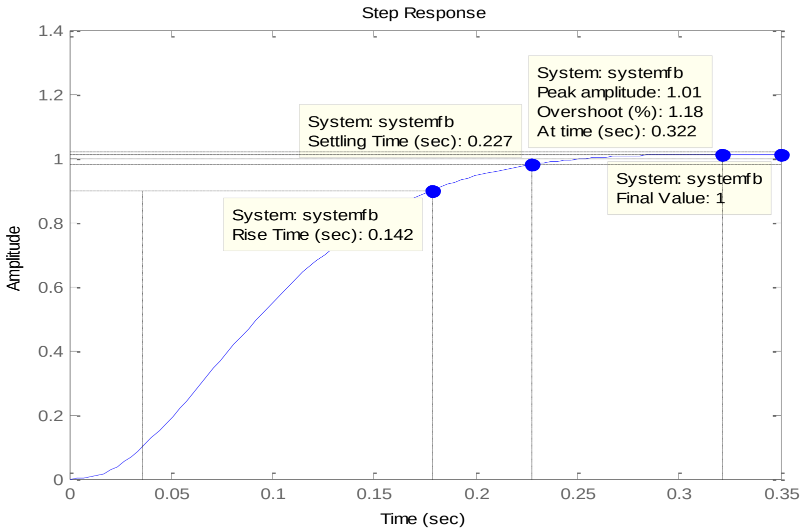

Fig. 5. Step response of the compensated system

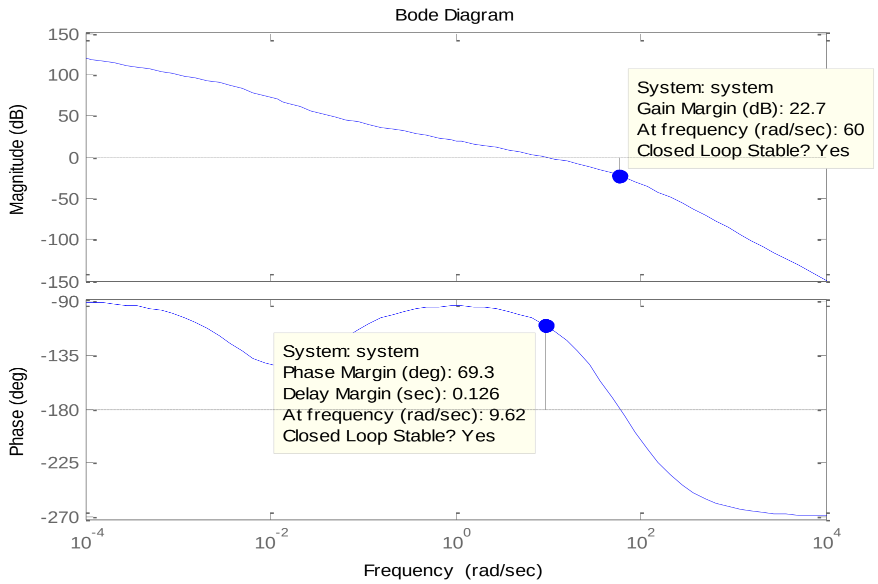

Fig. 6. Bode plot of the compensated system

7. CONCLUSION

Towing is an operation in various industries which require close control. The automatic control system chosen for them must satisfy stringent control requirements. The requirements are on steady state accuracy, t-domain and f-domain performance. To maintain the specified steady state accuracy, the forward path gain has to be increased. This increase in gain may make the system unstable or give rise to highly oscillatory response violating constraints on peak overshoot and other t-domain variables as well as reducing the margins of stability. Therefore, a compensator has to be added either in the forward path or in the feedback path. In this example of towing, a lag type compensator has been used in the forward path for its various advantages. The parameters of the compensator have been chosen judiciously so that the t-domain and f-domain specifications are matched. A cut and try process generally gives the desired performance (which may be noted from the results obtained using MATLAB). However, computer programs may be used to find out the parameters of the optimal compensator.

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