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Stability Improvement in Automobile Driving Through Feedback Loop and Compensator

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Abstract – *The paper gives the mathematical model of an automobile along with its driver. The automobile has been modelled from the standpoint of mechanics and the man driving the car has been modelled from the standpoint of physiology. The later contains a time delay. The directional control through steering has been considered as a closed-loop process. Analytical treatment of the control system has been made by replacing the delay element by a zero based on binomial approximation and the stability of the system has been ensured for the given gain. MATLAB tools have been used for the analysis. However the design specs could not be fulfilled. To compensate the system rate feedback was tried but desired results could not be obtained. So a lag type compensator was inserted in the forward path which could successfully meet the requirements. The design was made using SISOTOOL of MATLAB.*

Keywords *– Automobile, Driver, Feedback Loop, Time Delay, Compensator*

I. Introduction

Driving an automobile is, in essence, a feedback process [1,2]. This is an automatic control system in which the driver is to maintain a desired direction which dynamically varies. The feedback is through the eyes of the driver [4] which is transmitted to the brain. The error signal produced by the brain is amplified through muscles of the driver which controls the steering wheel. The automobile is modeled from the point of view of mechanics. The human transfer function, modelled by physiologists [8], is to be included as an element of the system.

II. Description Of The System

The block diagram of the system is given in fig. 1. The human transfer function includes a time delay element. The proportional feedback (unity) has been augmented with a rate feedback. The task is to maintain the desired direction in presence of the time delay. There must be adequate stability margin and the time-domain response must be acceptably good [3].

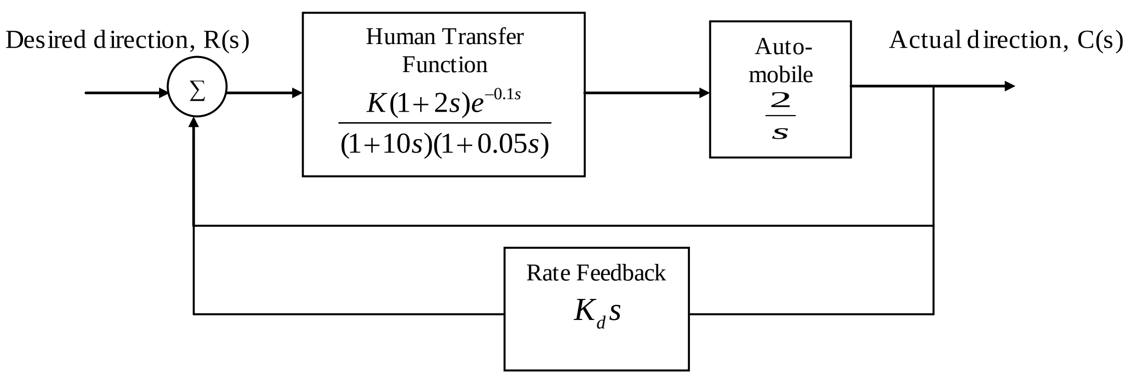

Fig 1 Driving an automobile: block diagram

Design specifications:

The control system must meet with the following specifications:

- The steady state error must be less than 1%
- The maximum overshoot must be limited to 4 %
- The settling time must be less than 15 sec.
- The gain margin must be more than 30 db and the phase margin more than 60°.

III. Mathematical Approach

The transfer function of the system inclusive of the human element is given below:

$$G(s)=\frac{C(s)}{R(s)}=\frac{2K(1+2s)e^{-0.1s}}{s(1+10s)(1+0.05s)}\ ;\ H(s)=1 \qquad (1)$$

The delay element does not affect the gain. It only causes a phase lag of (-0.1ω) rad.

This problem can be dealt with by linear control system analysis in two ways viz.

a. By excluding the time-delay and taking the transfer function as [1]:

$$G_1(s)=\frac{2K(1+2s)}{s(1+10s)(1+0.05s)} \qquad (2)$$

The (-1+j.0) point has to be shifted to: $-1.e^{-0.1(j\omega)}$ The solution can be made using Nyquist plot. The Nyquist plot of $G_1(j\omega)$ must not enclose the point $[-1.e^{-0.1(j\omega)}]$ and the phase margin is to be measured from the line joining this point with the origin.

b. Replacing the time-delay by an equivalent zero in the right half of s-plane (bionomial approximation) [2], as given in eqn. 3.

$$G(s)=\frac{C(s)}{R(s)}\approx\frac{2K(1+2s)(1-0.1s)}{s(1+10s)(1+0.05s)} \qquad (3)$$

The second method is more convenient and it does not give rise to much error. For ease and flexibility in handling the problem, we have used MATLAB tools for analysis.

IV. Analysis Using Matlab-Tools

Now, MATLAB tools are being used for analysis and design of the control system. At first, we shall consider the uncompensated system [5,6].

a. The uncompensated system

The forward path gain has been chosen as 3.75 by cut and try process. The time delay has been approximated as: $e^{-0.1s}=1-0.1s$; its effect is to add a zero in the right half of the s-plane. The t-domain response to a step input is given in fig. 2 and the corresponding Bode plot in fig. 3. It is observed that the peak overshoot is 14.8% and the peak time is 2.17 sec. The rise time and the settling time are 0.73 s ad 5.51 sec, respectively. The gain margin is 16.3 db and the phase crossover occurs at 13.7 r/s. The phase margin is 62.6^o and the gain crossover occurs at 1.58 r/s.

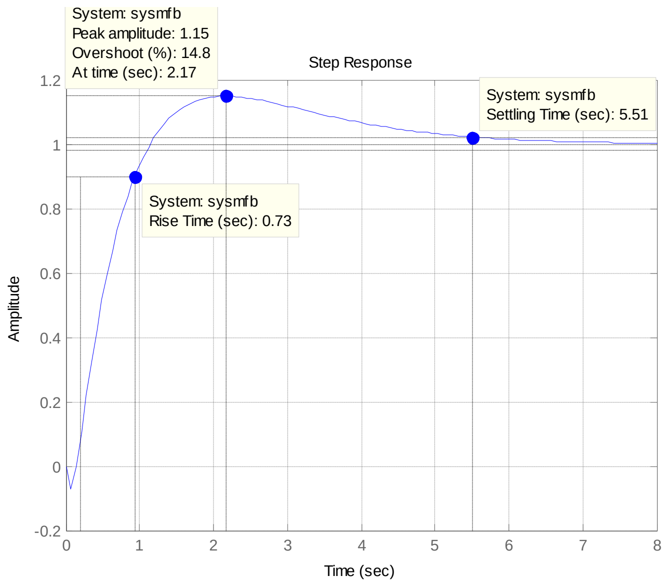

Fig. 2. Step Response of the uncompensated system.

It is noted that the uncompensated system gives a highly oscillatory response. This is not acceptable. Also the gain margin is below the specified value. So we add a rate feedback: $K_d = 0.07$. The forward path gain has been kept at the same value.

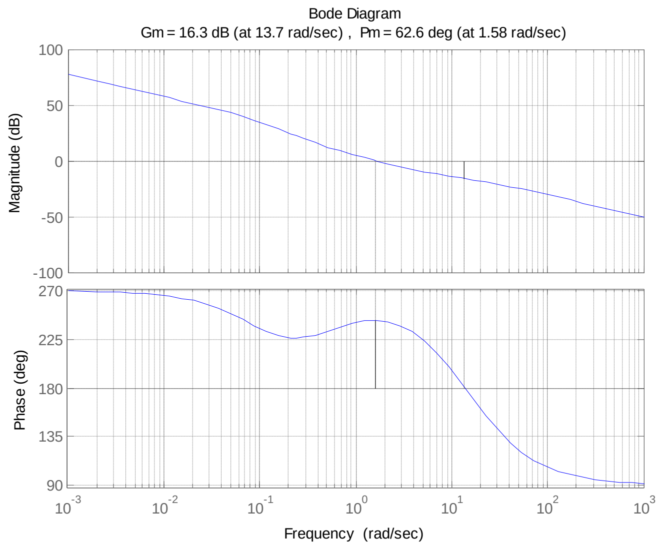

Fig 3. Bode Plot of the uncompensated system

b. Addition of rate feedback

In order to fulfill the design specifications, we are now adding a rate feedback. The aim is to reduce the peak overshoot. The adjusted value of rate feedback coefficient, $K_d = 0.07$. The t-domain response of the system with rate feedback is given in fig. 4 and the corresponding Bode plot in fig. 5 [5,7].

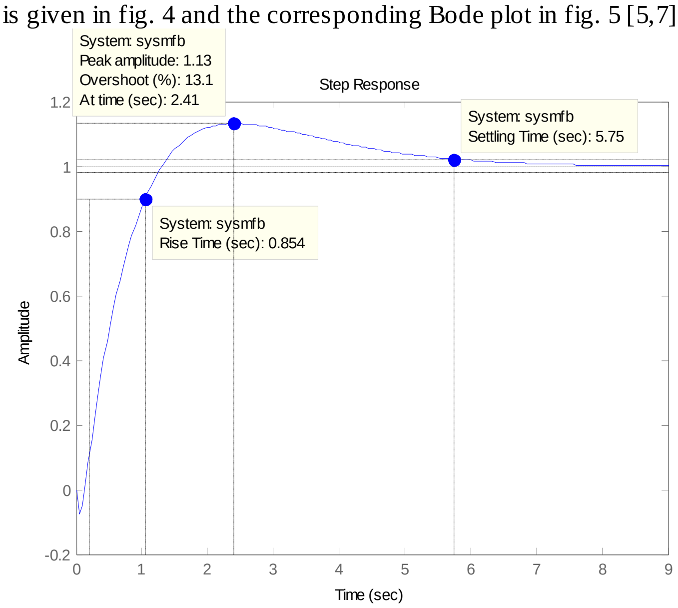

Fig. 4 Step Response with rate feedback

It is observed that the peak overshoot has only slightly reduced from 14.8% to 13.1% but the peak time has increased from 2.17 sec to 2.41 sec. The rise time has also increased from 0.73 sec to 0.854 sec. The settling time is now 5.75 sec. as against 5.51sec for the uncompensated system. It is noted that the addition of rate feedback has made the system sluggish but there has been no appreciable reduction in the percent overshoot. The gain margin has reduced. It is now 13.6 db as compared to 16.3 db for the uncompensated case. The phase margin has slightly increased- it has become 68.9^{o} as against 62.6^{o} for the earlier case.

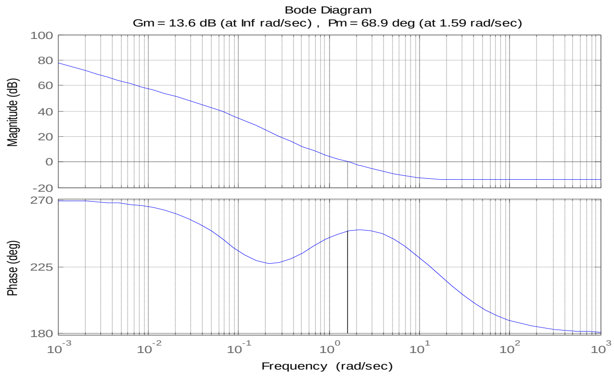

Fig. 5: Bode plot with rate feedback

Increasing the coefficient of rate feedback will tend to make the overshoot lower but the system will be unacceptably sluggish. So we have to think about cascading a compensator in the forward path. As the specifications have not been fulfilled even by using rate feedback, we are adding a lag compensator in series in the forward path and exclude the rate feedback.

c. Addition of a compensator in the forward path

The design is being made by using SISOTOOL of MATLAB. The design configuration is given in fig. 6. The gains, poles and zeroes of the fixed and tunable elements are given in table-I. [5]

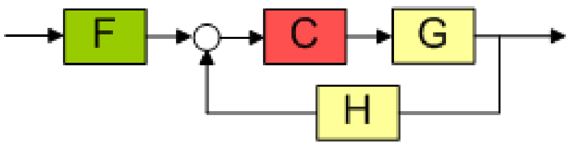

Fig. 6: The system with compensator cascaded in the forward path

Table-I

Items	Tunable elements		Fixed elements	
	C	F	G	H
Gain	0.144076	1	-3	1
zeroes	-0.081837	[ ]	[10; -0.5]	[ ]
Poles	-0.250987	[ ]	[0 ; -20; -0.1]	[ ]

The root locus, closed and open loop Bode plot of the lag-compensated system are given in fig.7 and the time domain response against step input and the open loop Bode plot are given in fig. 8.

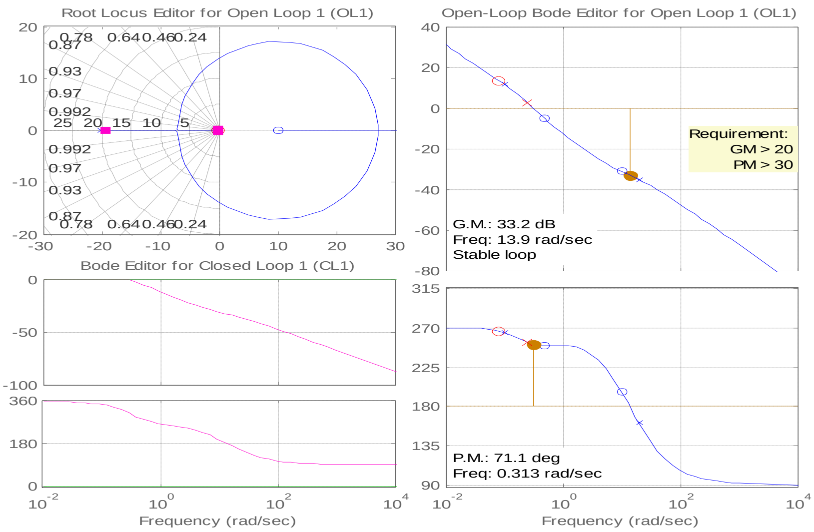

Fig 7 Root locus, closed and open loop Bode plot of the lag-compensated system

For the lag-compensated system, the peak overshoot is now only 3.71% and the peak time 10.5 sec. The settling time is 13.6 sec. The gain margin is 33.2 db and the phase margin is 71.1°. It is noted that the system with lag compensator cascaded in the forward path has been able to meet all the design specifications.

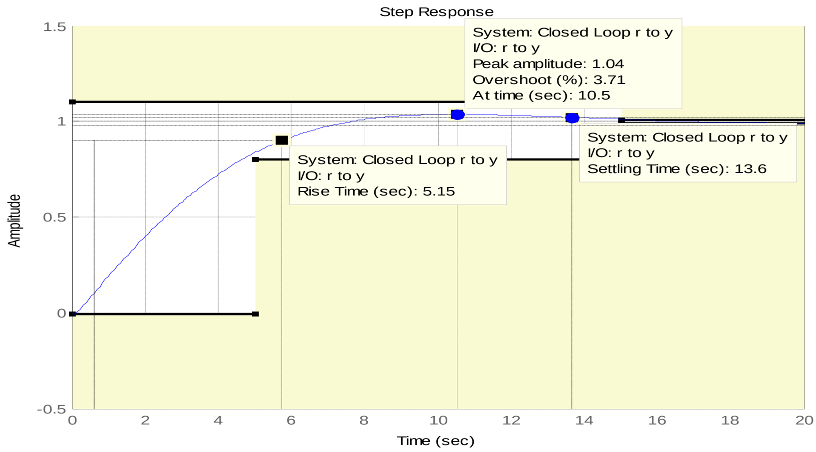

Fig 8 Time response and open loop Bode of the lag-compensated system

V. Conclusion

The paper deals with an automobile driving. The automobile has been modeled along with its driver. The combination has been treated as a closed loop system. The automobile has been modeled as an integrator and a gain. The driver has been modeled by a human transfer function, developed from the standpoint of physiology [1,2,8]. It contains a time delay element.

The system has been analyzed by MATLAB tools [5,6,7]. It has been found that the uncompensated system fails to fulfill the design specifications. Then an adjustable rate feedback has been added. But it also fails to fulfill the specifications, rather it makes the system sluggish. Hence rate feedback has been omitted and a lag compensator has been added in the forward path. The design has been made by using SISOTOOL of MATLAB7.9. The peak overshoot now comes down below 4%, settling time below 15 sec. and the requirements of gain and phase margin are fulfilled. So, design approach through SISOTOOL appears to be the best.

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