SINGLE PARAMETER TESTING

NAS8-11715, PART III

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1.0 INTRODUCTION

This report is an addendum to "Single Parameter Testing, Final Report", NAS8-11715, Part III. The systems which were tested and described in that report were linear systems. One of the systems was the thrust vector control system of the Saturn IB. This addendum report describes the testing results obtained with a non-linear model of this control system.

The objective of single parameter testing is to test several individual parameters of a system with one testing signal, thereby obtaining faster checkout time, better accuracy, and less degradation of performance due to testing. The study program to achieve this objective was divided into three specific tasks:

Phase A: The development of methods to test simple first and second order linear passive networks whose transfer functions resemble those of actual systems.

Phase B: The investigation and selection of criteria developed in Phase A. Extend the application of the method to include linear active networks.

Phase C: Investigate testing implementation problems, by studying the pen position control system of an X-Y plotter with the techniques developed in Phases A and B. Extend the testing techniaue to higher order systems.

The results from these three phases were reported in the corresponding phase reports and the final report (References 1 through 4). The Phase C extension task which this addendum report describes can be stated: Apply the developed single parameter testing technique to a non-linear model of the thrust vector control system which was the sixth order system studied in Phase C.

To briefly outline the steps necessary to implement the single parameter testing technique:

1. Develop a nominal system response. This response can be determined by the statistical measurement of a number of good systems. Once the nominal response is determined it can be stored on tape.

2. Develop a system model which can be used in the determination of an estimator. Good methods are available for this system transfer function determination.

3. The estimator is determined by a theoretical method as described in Reference 4 for first and second order transfer functions or by experimental techniques for higher order systems.

4. The fourth step is the implementation of the technique with the actual hardware to be tested keeping in mind impedance and signal level matching considerations.

2.0 SYSTEM DESCRIPTION

The sixth order thrust vector control system which was chosen for testing is described in Reference 5. The system uses a Moog's Model 16-120A dynamic pressure feedback servovalve and Moog's Model 17-150 actuator. A non-linear block diagram of the system and the nominal parameter values are given in Figure 1. This non-linear system was modeled on the analog computer and impulsed and the response obtained is shown in Figure 2. The ripple which appears on the oscillograph recording is a result of the "dither" signal

$$F_L = 7,700 + 15,000 (\sin 500t).$$

The linear emperical block diagram for the system is shown in Figure 3.

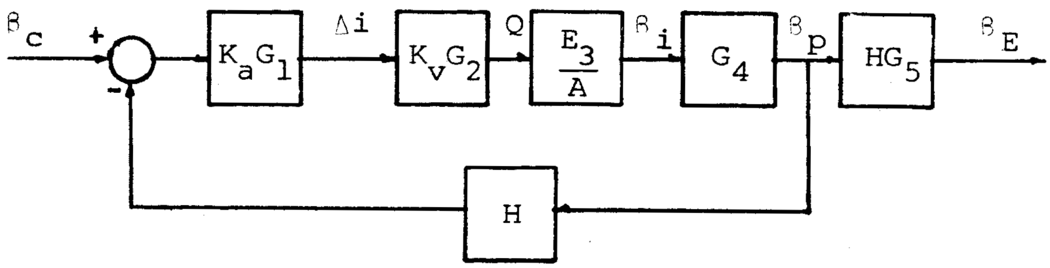
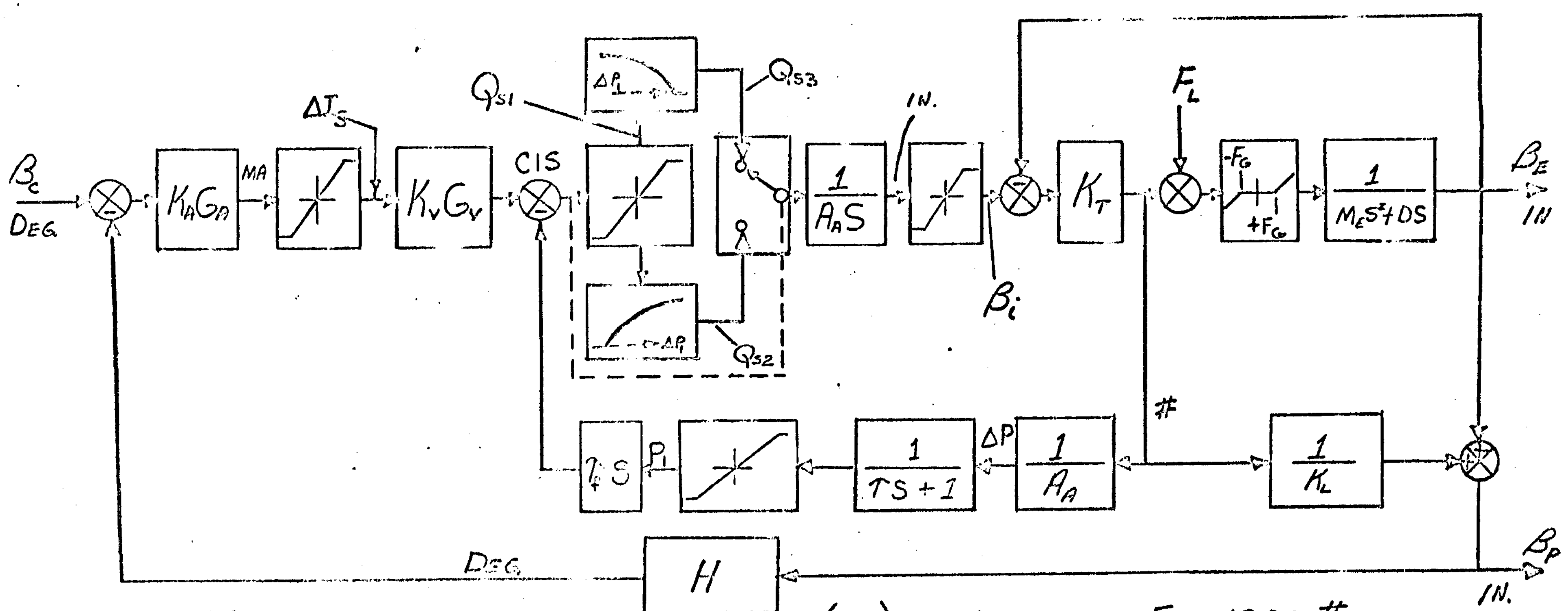


Figure 3

Emperical Block Diagram

S-1B

THRUST VECTOR CONTROL SYSTEM
NON-LINEAR BLOCK DIAGRAM



$K_A = 8$ MA/DEG

$G_A = \dfrac{1}{\left[\frac{S^2}{(2\pi 43)^2} + \frac{2(0.7)S}{2\pi 43} + 1\right]}$

$K_V = 5.45$ CIS/MA

$G_V = \dfrac{1}{\left(\frac{S}{2\pi 50} + 1\right)}$

$A_A = 5$ IN²

$K_T = 57{,}910$ #/IN

$K_L = 66{,}800$ #/IN.

$M_E = 16.1 \frac{\# \, SEC^2}{IN}$

$D = 34.25 \frac{\# \, SEC}{IN}$

$T_f = 6.37 \times 10^{-4}$ SEC

$T = \frac{1}{2\pi(3)}$

$H = 2.092 \frac{DEG.}{IN.}$

$P_S = 3{,}000$ PSI (NOM.)

$(\Delta I_S)_{MAX} = \pm 16$ MA

$(Q_{S1})_{MAX} = \pm 65$ CIS

$(\beta_i)_{MAX} = \pm 3.82$ IN.

$\dfrac{Q_{S2}}{Q_{S1}} = \left(\dfrac{P_S + \Delta P}{P_S}\right)^{1/2}$

$\dfrac{Q_{S3}}{Q_{S1}} = \left(\dfrac{P_S - \Delta P}{P_S}\right)^{1/2}$

$F_G = 1800$ #

$F_L = 7{,}700 + 15{,}000$(SIN 500·

$-P_S < \Delta P_1 < +P_S$

$-1750 < P_1 < +1750$ PSI

FIGURE 1

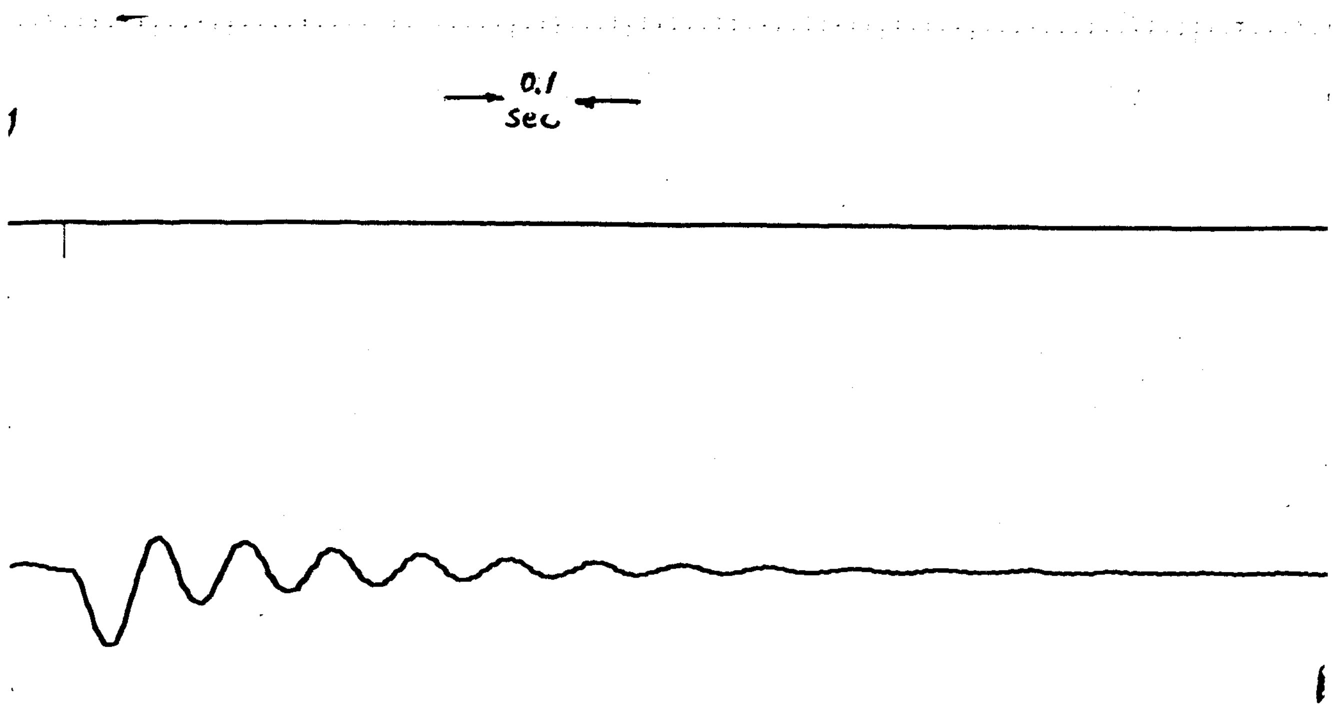


Figure 2

Impulse Response of Thrust Vector Control System

The magnetic amplifier transfer function is

$$K_a G_1 = \frac{K_a}{\frac{s^2}{(270.02)^2} + \frac{2(0.52)s}{270.02} + 1}$$

The servovalve transfer function is

$$K_v G_2 \quad \frac{K_v}{\frac{s}{314} + 1}$$

The actuator transfer function is

$$\frac{G_3}{A} = \frac{1}{AS}$$

The reflected load transfer function is

$$G_4 = \frac{\frac{s^2}{(64.68)^2} + \frac{2(0.08)s}{(64.68)} + 1}{\frac{s^2}{(53.38)^2} + \frac{2(.25)s}{(53.38)} + 1}$$

And the load transfer function is

$$HG_5 = \frac{H}{\frac{s^2}{(64.68)^2} + \frac{2(0.08)s}{(64.68)} + 1}$$

The overall system transfer function is

$$\frac{\theta_E}{\theta_C} = \left[\frac{1}{\left(\frac{S}{21.02}+1\right)\left(\frac{S}{302.519}+1\right)\left(\frac{S^2}{49.52^2}+\frac{2(.202)S}{49.52}+1\right)}\right] \bullet$$

$$\bullet \left[\frac{1}{\frac{S^2}{262.73^2}+\frac{2(.528)S}{262.73}+1}\right]$$

This is the linear system transfer function which was tested in Phase C and reported in Reference 4. The non-linear model which it represents is shown in Figure 1.

3.0 SINGLE PARAMETER TESTING RESULTS

Two single parameter testing techniques were developed during Phase A, B and C of the study. The one used to study the non-linear thrust vector control system model was the time sampling technique. This is similar to the technique described in Reference 5. The block diagram of the required test setup is shown in Figure 4.

The test signal for this time sampling technique is formed by recording the impulse response of the nominal system (see Figure 2) on tape and then reversing the tape end-for-end. Thus when the reversed signal is fed back into the system the actual impulse response of the system is cross-correlated with the desired impulse response.

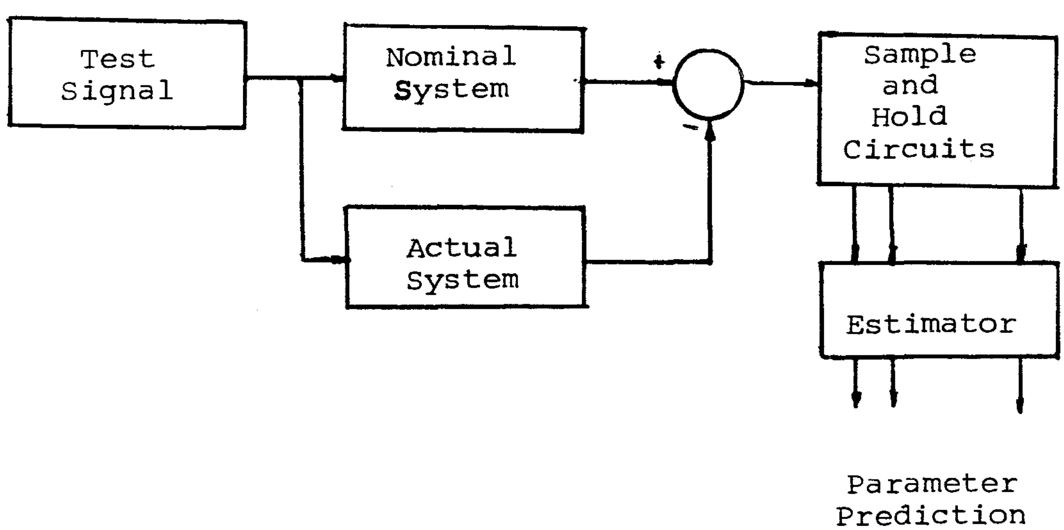


Figure 4

The Time Sampling Test Setup

The sampling times are selected by plotting the difference circuit output as a function of a given parameter change on an X-Y plotter. An example of this plot for changes in a given parameter (Δp) is shown in Figure 5. Note that at time t_1, the value of the error function is zero regardless of the size of the parameter change. This shows the high linearity of the error function, that is

$$E(t, \Delta p) \approx k_1(t) \Delta p$$

This time t_1 is selected as one of the sampling times. Another example plot is shown in Figure 6. Note that there is no one time where this error function is zero regardless of the parameter change. This indicates the necessity of higher order terms to express the error function, that is

$$E(t, \Delta p) \approx k_1(t) \Delta p + k_2(t) \Delta p^2$$

Two sampling times are selected from the plot as follows. One sampling time is chosen such that $k_1(t)$ is zero at this time instant and the other time such that $k_2(t)$ is zero. This then is how the sampling times are selected for the parameters of interest.

Several parameters in the non-linear thrust vector control system including some of the nonlinearities were considered for testing. As had been noted in previous testing, some parameters are much easier to measure than others. That is, the error response may be much more sensitive to a given percentage change is one parameter, than another.

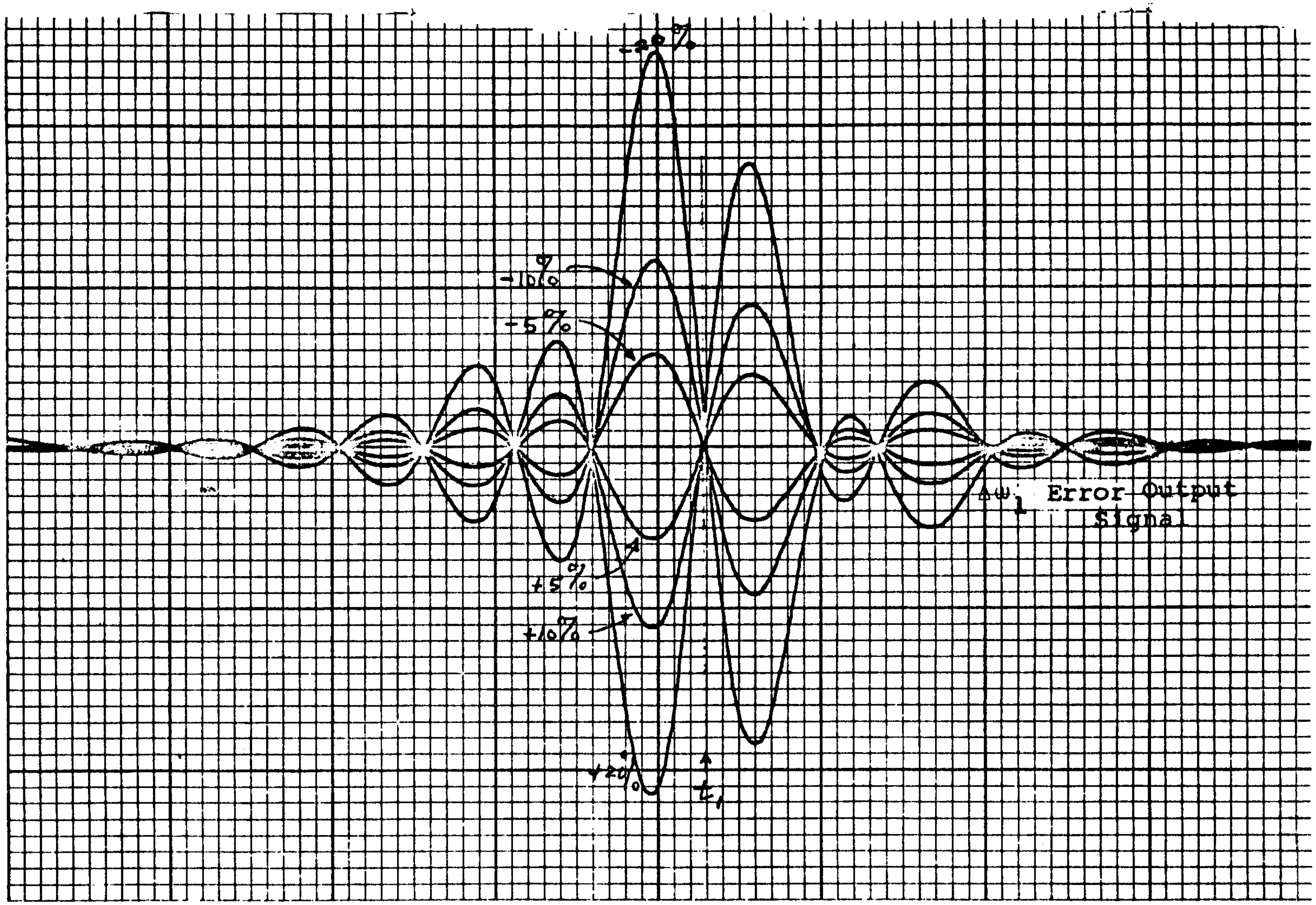


Figure 5

Results from the Time Sampling Test Setup

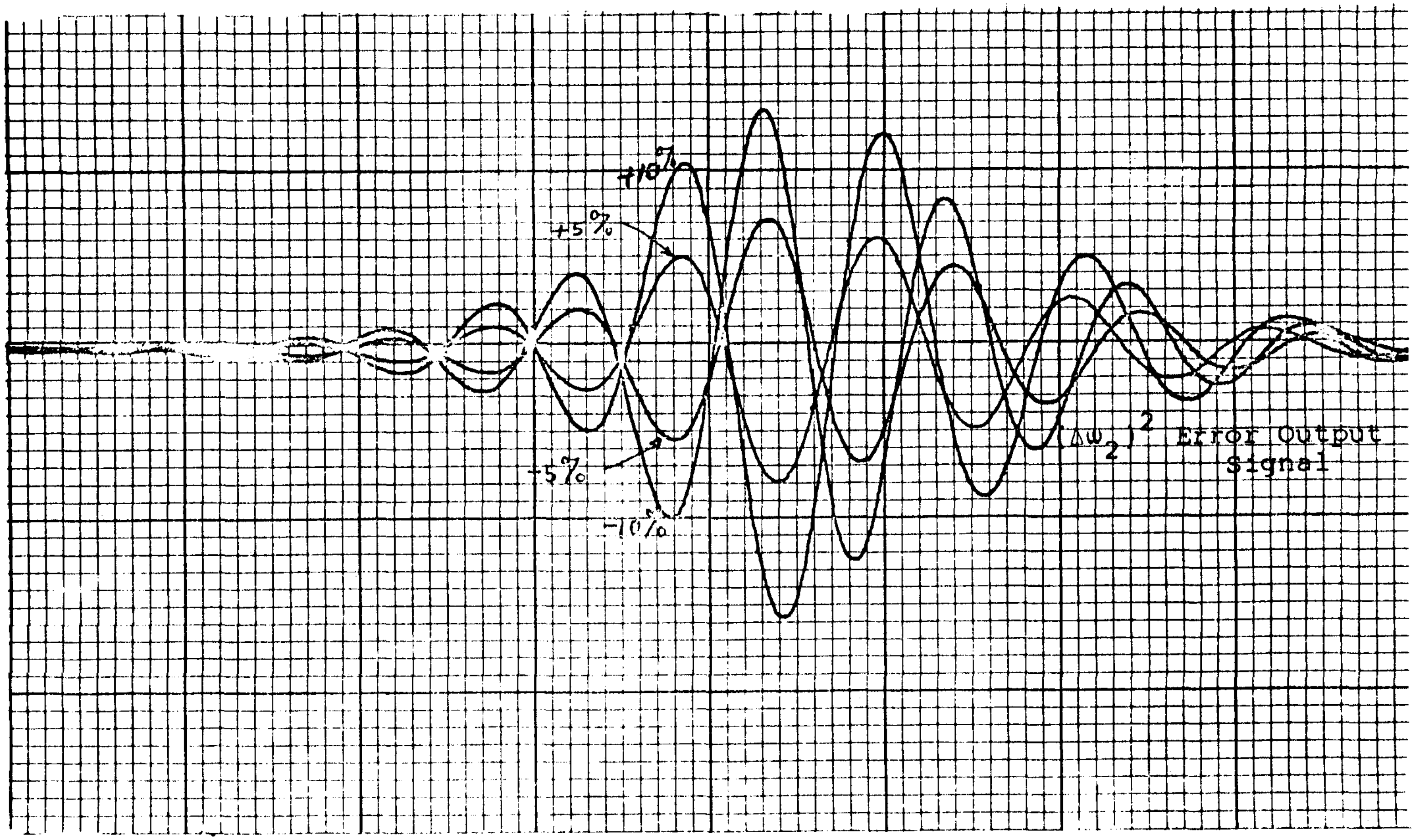


Figure 6

Results from the Time Sampling Test Setup

The parameters which were measured with the testing setup are shown in Table 1.

PARAMETER	NOMINAL VALUE
Servovalue frequency (ω)	50 CPS
Servovalue gain (K_V)	5.45 CIS/MA
Load (M_E)	16.1 LB SEC^2/IN
Nominal Pressure (P_S)	3000 PSI
Flow Rate Limit (Q_S)	$\pm$ 65 CIS

Table 1

Parameters to be Measured

The error functions for these five parameters were plotted and the sampling times were selected. The parameters all showed a high degree of linearity and therefore only five sampling times were used. The modulation matrix which was obtained is given in Table 2 and inverting this matrix gives the estimator to be used in the test setup.

$$\begin{bmatrix} E(t_1) \\ E(t_2) \\ E(t_3) \\ E(t_4) \\ E(t_5) \end{bmatrix} = \begin{bmatrix} .45 & -0.2 & -0.8 & -2.0 & 0 \\ .90 & 0.2 & 5.3 & 0 & 0.4 \\ .17 & 2.2 & 0 & 1.86 & +3.2 \\ -.22 & 0 & -0.2 & -2.0 & -0.4 \\ 0 & -1.4 & 4.6 & -2.6 & -2.8 \end{bmatrix} \begin{bmatrix} \Delta\omega/.2 \\ \Delta K_V/.1 \\ \Delta M_E/.1 \\ \Delta P_S/.1 \\ \Delta Q/.2 \end{bmatrix}$$

Table 2

Modulation Matrix

The results obtained with the test setup established that single parameter testing using time sampling can be used on non-linear systems and that some non-linearities can be measured. Certain non-linearities such as the deadband and the 500 rad/sec sine wave in the load part of the non-linear block diagram act like a gain change in the loop and therefore can not be distinguished from a gain change. The limiting action on the flow rate (+65CIS) and the current limitation of ± 16 ma could be measured however.

When the linear model was tested as reported in Reference 4, it was found that the range over which accurate measurements could be made was for parameter changes of ± 10%. This range of ± 10% remained the same for the non-linear model testing. The average accuracy of the parameter prediction with the linear model was two to three percent for parameter errors within the measurement range. The parameter prediction with the non-linear model can be made with an average accuracy of three to five percent. The reason for the decrease in accuracy was not the non-linearities in the model but problems associated with the increased complexity of the model. This made it difficult to obtain an accurate match between the actual and nominal system with all parameters at the nominal value. This matching problem increases as the complexity of the system increases. The ability to repeat a given run from day to day also becomes a problem with increasing complexity. Small differences from run to run can even be observed and these problems led to the measurement inaccuracies. These observations apply to models built on the analog computer but they would be equally applicable to actual hardware equipment.

4.0 CONCLUSIONS

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This Phase C extension study has established that single parameter testing using time sampling can be performed on non-linear systems. Certain non-linearities can be predicted by this technique. The range over which accurate parameter predictions can be made was the same for the testing of both the linear and non-linear model of the thrust vector control system. The accuracy of the parameter prediction was less for the non-linear system. The reason for this was the complexity of the system model, however, and not the fact that the system contained non-linearities. The system complexity led to problems in matching the nonimal system to the actual system under zero parameter error conditions and problems in data repeatability.

Author

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