OPTIMUM REDUCTION OF LARGE CONTROL SYSTEMS

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By

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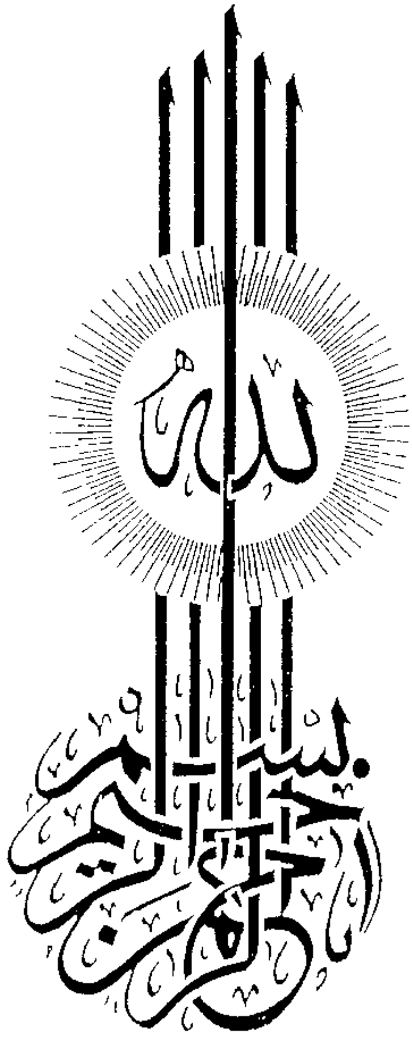
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ABSTRACT

This thesis is concerned with the simplification of large systems using models having lower orders than the original one. Two main approaches are considered.

The first approach is based on obtaining the eigenvalues and eigenvectors of the original system and then retaining only the effect of the dominant ones in the model response. The necessary modifications are introduced so that the steady states of the state variables retained in the model and the original one are the same.

An extension to that approach is also presented which is based on dividing the total response time to three intervals. We then retain only those eigenvalues of the system which have a dominant effect on the transient response during the time interval of interest. Therefore, three simplified models, each valid over a certain interval of time, are used to represent the original system.

In the second approach a discrete model is obtained in which the number of state retained are those which are available for measurements. The model is represented by its driving and transition matrices which are selected such that the response of the system and the model are nearly the same at some selected points in time.

All the above procedures were applied for a boiler system having nine state and five input functions. Computational results were given for each method and different orders for the reduced models were considered.

CONTENTS

CHAPTER (1)

INTRODUCTION

Modern control theory which is based [1] on state space concepts is extremely useful for designing systems with performance characteristics that cannot be achieved by the classical approach using the frequency response or the root locus methods.

The first step in analysis and synthesis of a control system is the development of a suitable mathematical model of a given plant. A mathematical model of a plant can, in principle, be obtained from the structure of the plant and the properties of the individual elements of the plant together with fundamental physical laws governing its behavior. A suitable model is a compromise between the mathematical difficulty attached to complicated equations and accuracy derived in the final result. Equations describing the plant dynamics can often be approximated by ordinary differential equations with number depends on the complexity of this plant and the accuracy required.

A complex plant is usually characterized by multiple inputs and outputs. A reasonably accurate and complete descriptions of the plant may, in some cases, result in over a hundred first-order differential equations. Reducing these to the essential equations by hand is laborious even in the simplest case and impractical is most cases. Without reduction we may not be able to study a complex system especially when it is desired to apply modern control theory and derive optimal feedback laws which in general depends on the availability of all state to the feedback controller.

It is therefore essential to develop systematic methods for reducing system order. Several techniques have been developed to handle this problem. Two main approaches are now in existence. The first one depends on the evaluation of the eigenvalues and eigenvectors of the original systems, while the second one avoids this by trying to compute the transition and driving matrices based on matching a selected number of state variables of the original system with a corresponding number of variables for the reduced model.

Organization of the thesis:

The work covered by this thesis can be summerised as follows:

In chapter (2), the dynamic equations of a boiler unit are derived. Linearization about steady-state operating conditions is then performed to obtain a linear dynamic model for the unit consisting of nine state variables and five control functions. This model will be the subject of simplification in the following chapters.

In chapter (3), a method is presented for approximating a system of high order with one of a lower order. The method is based on neglecting the eigenvalues of the original system which are farthest from the origin and retain only dominant eigenvalues and hence the dominant time constants of the original system in the reduced model. The over all dynamic performance of the reduced system will approximate that of the original system but the steady state values of the reduced system will not be identical to the steady state values of the original system. This model is then modified to give a correct steady state response for step inputs. In this chapter we applied these methods for reducing the original 9 states of the boiler unit to 4, 5 and 6 state models.

In chapter (4) a method is proposed by which a large system can be reduced to a number of simplified models by dividing the total response time into a number of smaller intervals. This division is based on the relative magnitudes of the eigenvalues of the original system. This method can be used to determine the final, initial and intermediate transient responses of the system for various initial conditions of the state variable as well as for various forcing function. In this chapter we form 3 models for the poiler system, one for final transient response (6 state mode), another for initial transient response (6 state mode) and a third one for intermediant transient response (3 state model).

In chapter (5) we discuss a method which avoids the computation of the eigenvalues and eigenvectors. A discrete representation of the system dynamics is used. The discrete transition and driving matrices of the model are matched with the corresponding original variables at a finite number of points. In this chapter we applied this method to reduce the original boiler model to 4 and 6 state models.

CHAPTER (2)

DERIVATION OF THE DYNAMICAL EQUATIONS FOR A BOILER SYSTEM

2.1 System Description:

In this chapter the dynamic model of a boiler unit operating in an industrial power station will be derived [2]. The boiler used is an oil-fired unit with a capacity of 100,000 lb/h, and operates at 650 lb/in^2 gauge, 850°F. It is operated on natural circulation and is controlled to maintain steam pressure, steam temperature and combustion efficiency using conventional pneumatic controllers in independent loops. Proportional plus integral action, initiated by deviations from present values, is used for regulating fuel and air supplies. A constant steam-flow/air-flow ratio is maintained for optimum combustion efficiency.

2.2 Boiler Dynamics:

For determining a mathematical model, the boiler is assumed to consist of lumped energy - storage elements comprising two riser sections, a single super-heater section, steam drum and gas path. A schematic diagram for the boiler is shown in Fig. (1).

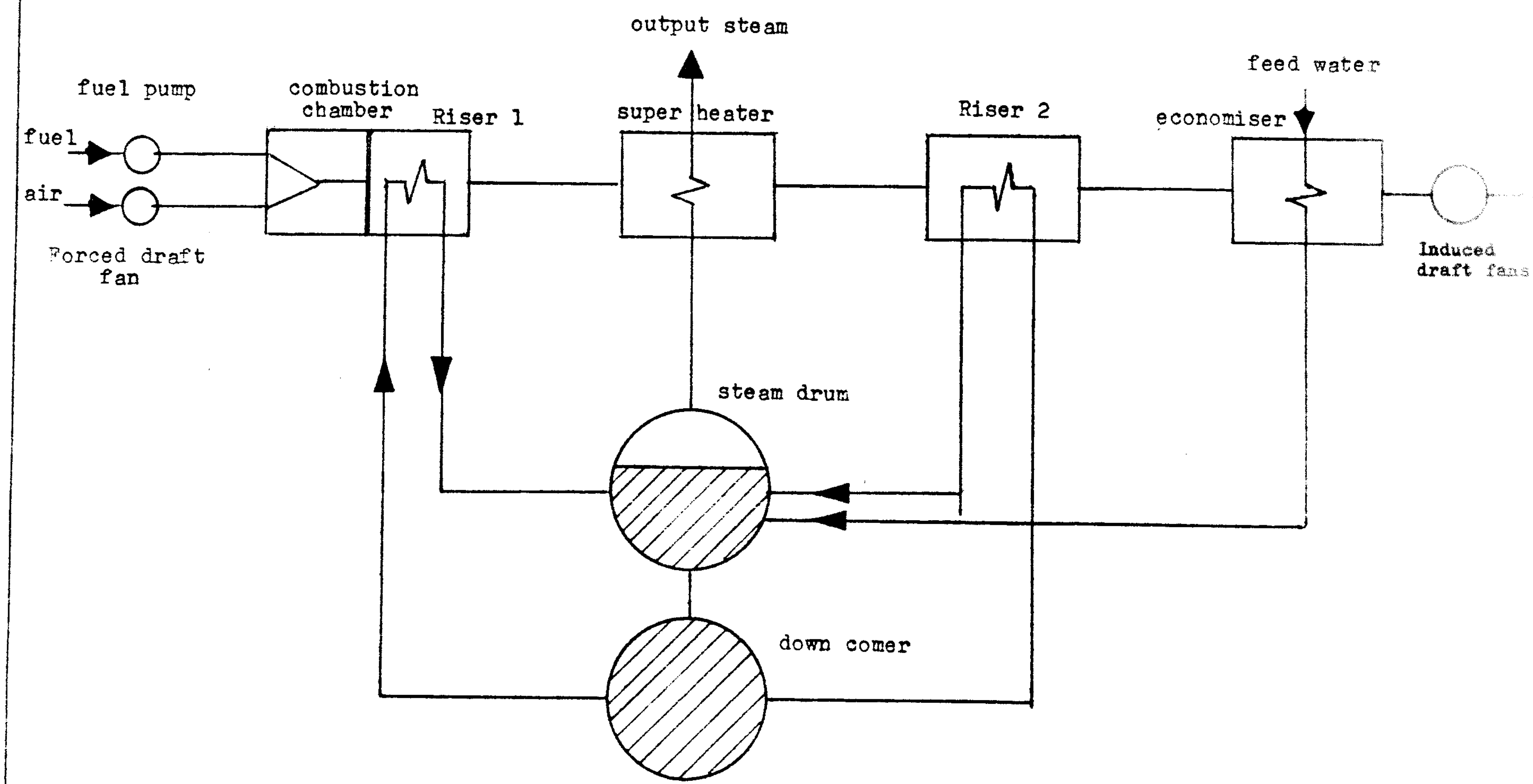

Fig. (1): Schematic diagram for the boiler unit.

The economiser is assumed to have little effect on transient performance and will be neglected in the following derivations.

2.2.1 Super-heater:

Mass balance:

$$w_v - w_s = V_s \; \dot{\rho}_s \qquad (1)$$

where

w_v , w_s is the mass flow of steam at risers and super-heater.

$V_s = A_s \, L_s$ is the volume of steam at super-heater.

ρ_s = is the steam density.

A_s and L_s are super-heater area, and tube length.

Friction loss:

$$P_v - P_s = f_s \quad w_v^2 / \; _v \qquad (2)$$

where

P_s, P_v = super-heated steam and vapor pressures.

ρ_v = saturated vapor density.

f_s = super-heater friction coefficients.

Gas tube heat balance:

$$Q_{gs} = Q_s + M_s\, C_{st}\, \dot{T}_{st} \qquad (3)$$

where

Q_{gs}, Q_s = steady state heat input rates from gas tubes to steam and boiling liquid.

M_s, C_{st} = mass and heat capacitance of super heater tubes.

T_{st} = super heater tube wall temperatures.

Turbulent heat transfer-tube-steam:

$$Q_s = K_s\, w_v^{0.8}\, (T_{st} - T_s) \qquad (4)$$

where

K_s = heat transfer coefficient from super heater tubes to steam.

T_s = super heater temperature.

Steam heat balance:

$$Q_s + H_v\, w_v = w_s H_s + V_s \frac{d}{dt} (\rho_s\, H_s) \qquad (5)$$

where

H_s, H_v = super heated steam and saturated vapour enthalpy.

2.2.2 Steam drum:

Liquid mass balance:

$$w_e + (1-x)\ w_r = w_d + w_{ec} + \frac{d}{dt}(V_w\ \rho_w) \qquad (6)$$

where,

w_r, w_d, w_e = mass flows of steam or water at risers, downcomers and economiser.

w_{ec} = drum liquid mass-evaporation rate.

x = riser outlet mixture quality.

Drum liquid mass:

$$M_w = V_w\ \rho_w \qquad (7)$$

where:

M_w , V_w are liquid mass and volume of steam drum.

ρ_w = liquid density.

Steam mass balance:

$$W_{ec} + x\ w_r = w_v + \frac{d}{dt}(V_v\ \rho_v) \qquad (8)$$

where

V_v = vapor-phase volume of steam drum.