Open access • Proceedings Article • DOI:10.23919/ACC.1990.4791218

Feedback Design of a Canonical Multivariable System with Application to Shape Control in Sendzimir Mills — Source link

John V. Ringwood, David H. Owens, Michael J. Grimble

Institutions: Dublin City University, University of Strathclyde

Published on: 23 May 1990 - American Control Conference

Topics: Square matrix, Eigenvalues and eigenvectors, Invertible matrix and Matrix decomposition

FEEDBACK DESIGN OF A CANONICAL MULTIVARIABLE SYSTEM WITH APPLICATION TO SHAPE CONTROL IN SENDZIMIR MILLS

J.V. Ringwood*, D.H. Owens** and M.J. Grimble***

* School of Electronic Eng., Dublin City University, Glasnevin, Dublin 9, Ireland.

** Dept. of Dynamics and Control, University of Strathclyde, Glasgow G1 1XW, Scotland.

*** Industrial Control Unit, University of Strathclyde, Glasgow G1 1QE, Scotland.

ABSTRACT

The shape control problem, for a Sendzimir Cold Rolling Mill, is multivariable. The plant transfer function matrix, has the special form: $G(s) = g(s)G_m$, where $g(s)$ is a scalar transfer function and G_m a square matrix of constant gains. G_m, however, is not invertible, but the system is diagonalised using an eigenvector/eigenvalue decomposition resulting in a scalar frequency response design problem. An important consideration in shape control systems is the robustness of the design due to the wide range of materials rolled, reflected in changes in the elements of G_m. To this end, a development is included which represents the robustness of the design, with respect to errors in G_m, in terms of a set of strict inequalities.

1. INTRODUCTION

In shape control, the internal stress profile across a steel strip is measured at discrete (regular) points using differential tension measurements and influenced using bending of the mill rolls (Fig.1). Good shape control can substantially improve the material quality and reduce wastage. In the paper, it is shown that the plant inputs annd outputs should be transformed to give a reduced dimension problem and a suitable transformation is suggested by an inspection of the eigenvalue spectrum of the mill gain matrix, G_m. The transformations are similar in form to those chosen by Grimble and Fotakis [1] with process requirements in mind. The control law developed here, however, is computationally simpler and provides a natural basis for the robustness development.

The Sendzimir mill processess more than 3500 different material sizes and types. Since it is desireable to use one controller with a number of different mill schedules, it is important to have a measure of the allowable variations in G_m which retain stability (note that $g(s)$ is constant for a given strip speed).

2. SENDZIMIR MILL MODEL

The mill is modelled as an 8x8 matrix of (linearised) constant gains, G_m [2] (representing the relationship between the 8 hydraulic actuators (Fig.1) and the shape profile at the rollgap at the 8 modelled points) in series with a scalar dynamic element, $g(s)$ as:

$$G(s) = \frac{e^{-0.582\,s}}{(1 + 0.2s)(1 + 1.06s)(1 + 0.74s)}\, G_m \qquad (1)$$

The delay term represents the transport delay from the roll-gap to shapemeter, and the poles represent (from left to right) the (linearised) actuator, strip and shapemeter dynamics respectively. The coefficient values (strip speed dependent) are for medium strip speed (5 -> 10 m/s) [3].

3. FEEDBACK CONTROL DESIGN

An eigenvalue/eigenvector decomposition will be used to (pseudo-) diagonalise the system. A typical eigenvalue spectrum for G_m is (14.9, 9.9, 5.2, 1.4, 0.2, -0.06, -0.05, -0.006). The general profile of the corresponding first 4 eigenvectors follow 1^{st} -> 4^{th} order polynomial profiles respectively (see Fig.2). Note that the eigenvalues satisfy the seperation condition:

$$\mu_1 = \min_{1 \leq i \leq 4} |\lambda_i| \gg \max_{5 \leq i \leq 8} |\lambda_i| = \mu_2 \qquad (2)$$

The control objective is to design a unity negative feedback system (so that incoming strip disturbance profiles are offset), with forward path compensator $K(s)$. Ideally, G_m could be diagonalised by the transformation:

$$T^{-1} G_m T = \mathrm{diag}\,\{\lambda_1, \lambda_2, \ldots \lambda_8\} \qquad (3)$$

with a scalar precompensator $k_i(s)$ used to dynamically compensate each individual loop. However, the 'high-order' profiles are known to be difficult to control, since high gains (μ_2 is small) and high order bending (physically undesireable) are required. Therefore, in accordance with the seperation condition (2), the transformation matrices are partitioned as:

$$T = [T_1 \quad T_2] \quad , \quad T^{-1} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad (4)$$

where $T_1 , T_2 \in R^{8x4}$, $V_1 , V_2 \in R^{4x8}$

If an orthonormal eigenvector set is chosen,

$$G(s) = T_1 \, [g(s)\mathrm{diag}\{\lambda_i\}_{1 \leq i \leq 4}] \, V_1 + T_2 \, [g(s)\mathrm{diag}\{\lambda_i\}_{5 \leq i \leq 8}] \, V_2 \qquad (5)$$

$$= T_1 \, G_1(s) \, V_1 + T_2 \, G_2(s) \, V_2 \qquad (6)$$

Choose $K(s)$ so that the output contribution from the high order bending is ignored as:

$$K(s) = T_1 \, \mathrm{diag}\{k_i(s)\}_{1 \leq i \leq 4} \, V_1 \qquad (7)$$

(a) to reflect the fact that acceptable control gains will have little effect on the high order bending modes, and
(b) to avoid generating high order bending.

If the same response and accuracy in each loop is required, choose

$$\lambda_i k_i(s) = k(s) \quad , \quad 1 \leq i \leq 4 \qquad (8)$$

For a medium speed plant (as an example), $k(s)$ was determined from classical techniques to be:

$$k(s) = 0.4(s + 0.7)/(s + 0.001) \qquad (9)$$

Simulation results for the full nonlinear model show the performance of the controller. The input (disturbance) profile is constant (but nonzero) and the target (reference) shape profile is uniformely flat (for orders 1 -> 4). Fig.3 shows the shape profile variations with time and Fig.4 shows the parametric (parameterised profile) variations with time. Control is applied after 5 seconds and it can be seen that the transient and steady-state performance is satisfactory. Note that the residual profile in Fig.3 is of (relatively) high order.

4. A ROBUSTNESS RESULT

It is assumed that a precompensator matrix K(s) has been designed for a nominal plant $G(s) = G_m g(s)$, but that G_m is subjected to a matrix error, Δ. The stability of the system is described by the return difference as:

$$|I_8 + (G_m + \Delta)g(s)K(s)| =$$

$$|I_8 + GK| \, . \, |I_8 + (I + KG)^{-1}Kg\Delta| \quad (10)$$

dropping the s-dependence for clarity. A necessary condition on Δ to retain stability is thus:

$$|I_8 + (I + KG)^{-1}Kg\Delta| \neq 0 \quad \text{for } Re(s) > 0 \quad (11)$$

Noting that $KG = T_1 V_1 \; gk(s)$ and using the identity:

$$|I_m + AB| = |I_n + BA| \quad , \quad A \in R^{m \times n} \quad , \quad B \in R^{n \times m}$$

the condition in (11) may be replaced by:

$$|I_4 + (1+gk)^{-1} gk\{\lambda_i^{-1}\} V_1 \Delta T_1| \neq 0 \text{ for } Re(s) > 0 \quad (12)$$

This condition may be replaced by a frequency independent sufficient condition based on the fact that a diagonally dominant matrix is nonsingular:

$$1 > \sum_{j=1}^{4} \sup_{\omega > 0} |F_{rj}(j\omega)| \quad , \quad 1 \leq r \leq 4 \quad (13)$$

where

$$F(s) = (1 + gk)^{-1} gk \; V_1 \Delta T_1 \quad (14)$$

since F(s) is strictly proper and analytic and bounded in the interior of D. Such a condition may be expressed in elemental form as:

$$1 > \sum_{p=1}^{8} \sum_{q=1}^{8} c_{rpq} \, |\Delta_{pq}| \quad , \quad 1 \leq r \leq 4 \quad (15)$$

$$\text{and } c_{rpq} = \sup_{\omega > 0} |gk/(1+gk)| \sum_{j=1}^{4} |\lambda_r^{-1}| \, |(V_1)_{rp}(T_1)_{qj}|$$

The stability of the perturbed system is indicated by the four inequalities expressed in (15). Note that a Nicholl's chart may be used to determine the supremum over freq. The above robustness result has been shown [3] to be an accurate prediction for the stability of the perturbed system.

5. CONCLUSIONS

A diagonalizing precompensator, exploiting the natural bending modes present in the mill, has been developed. The compensator is computationally simpler than that of Grimble and Fotakis [1] (4 mults. Vs. 16 mults. and 12 adds.), since the transformations themselves perform the diagonalisation - K_1 merely equalises the dynamics in each path. A robustness result was developed to determine the allowable reduction in controller numbers and this is also useful in predicting allowable modelling inaccuracies in G_m.

REFERENCES

1. Grimble, M.J. and Fotakis, J. "The design of shape control systems for Sendzimir mills", IEEE Trans. Aut. Con., AC-27, 1982, pp 656-666.
2. Gunawardene, G.W.G.M. "Static model development for the Sendzimir cold rolling mill", Ph.D. Thesis, Sheffield City Polytechnic, U.K. 1982.
3. Ringwood, J.V. "The design of shape control systems for a Sendzimir mill", Ph.D. Thesis, University of Strathclyde, 1984.

ACKNOWLEDGEMENT

The authors are grateful for the support of GEC Electrical Projects, Rugby and BSC, Sheffield. We are grateful for the contributions to the project by Mr. A. Kidd of GEC and Mr. A. Bill and Dr. K. Dutton of BSC.

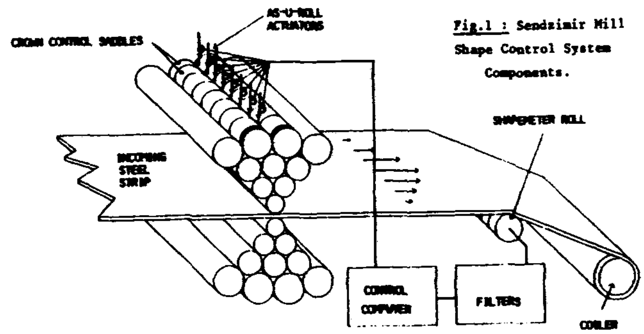

Fig.1 : Sendzimir Mill Shape Control System Components.

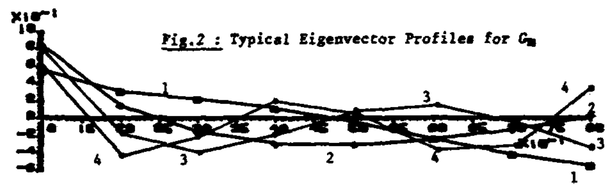

Fig.2 : Typical Eigenvector Profiles for G_m

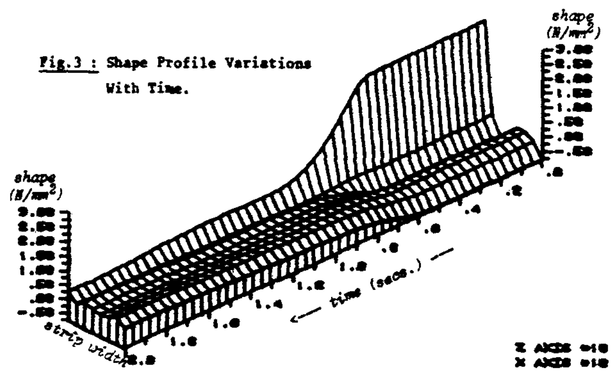

Fig.3 : Shape Profile Variations With Time.

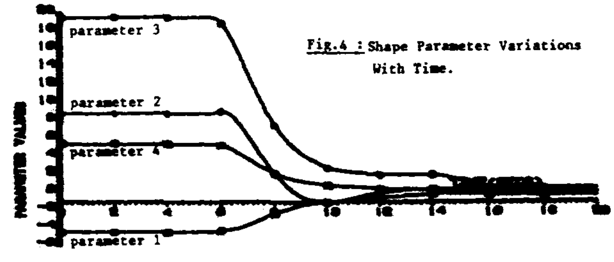

Fig.4 : Shape Parameter Variations With Time.