MATHEMATICAL MODELLING AND ANALYSIS OF RAILWAY PNEUMATIC BRAKE SYSTEM

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of the degree of
DOCTOR OF PHILOSOPHY

by
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CERTIFICATE

We are satisfied that the thesis entitled "Mathematical Modelling and Analysis of Railway Pneumatic Brake System", presented by S. Bharath is worthy of consideration for the award of the degree of Doctor of Philosophy and is a record of the original bonafide research work carried out by him under our guidance and supervision and that the results contained in it have not been submitted in part or full to any other university or institute for award of any degree/diploma.

We certify that he has pursued the prescribed course of research.

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ABSTRACT

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This work deals with the analysis of pressure transients in a pneumatic brake system used in rail road vehicles. The pneumatically operated brake system consists of a number of brake cylinders connected to a common air supply line namely, the train pipe. During braking, the pressure rise in the brake cylinder in each wagon, exerts the force on the piston working inside it. This force is transmitted to the wheels by a system of levers for brake application. It can therefore be seen that pressure transients in a pneumatic brake system need to be analysed in view of their influence on the braking characteristics of the system.

In order to predict the pressure transients, lumped and distributed nonlinear models have been formulated and analysed for emergency braking conditions. In all, five lumped mathematical models and two distributed mathematical models have been studied. The lumped system models, are

a MODEL - 1

Single capacity model, in which equivalent brake cylinder capacitance is obtained by lumping all the

brake cylinder capacitances, and equivalent train pipe resistance is obtained by considering all those train pipe resistances to be in series till the cylinder at which pressure rise is desired.

b MODEL-2

Multicapacity model, where only the resistance of the branch pipe connecting the brake cylinders to the train pipe and the resistance of the train pipe between brake cylinders of adjacent wagons are lumped. This model unlike the single capacity model predicts the pressure transient in every brake cylinder simultaneously.

c MODEL-3

Two capacity model in which the effects of the equivalent train pipe capacitance is also considered in addition to the equivalent brake cylinder capacitance. The equivalent train pipe capcitance is calculated considering the total volume of the entire train pipe. The rest of the features in this model are similar to those of single capacity model.

d MODEL-4

Multicapacity model, including the capacitance effects of the train pipe connecting the brake cylinders in adjacent wagons of the train. The lumped pipe capacitance is placed below the corresponding brake cylinder capacitance with the lumped branch pipe resistance between them. The other details are identical to those given in model 2.

e MODEL-5

Multicapacity model with varying brake cylinder capacitance effects, and auxiliary reservoir volume effects in its formulation. The other aspects are similar to those mentioned in model 4.

All the lumped models consist of a system of ordinary nonlinear differential equations which have been solved by the shooting technique. In model 5, in addition to the differential equations that describe pressure rise in the system, the second order equation of motion for the piston displacement in each cylinder gives the position of the piston in each cylinder during transient conditions. A study has also been made using model 4 to simulate brake release characteristics of the system.

The distributed system mathematical models have been formulated and studied not only to check the results obtained by lumped models but also to see if there are any improvements in the results obtained when compared to those obtained by lumped models. The distributed system models, are a MODEL-6

This model, in which the brake cylinder volume is kept constant, consists of one-dimensional partial differential equations for the train pipe and ordinary differential equation for the brake cylinder.

b MODEL-7

This model, which also includes varying brake cylinder volume effects and auxiliary reservoir volume effects, has in addition to governing equations of model 6, second order differential equation of motion for piston displacement in the brake cylinder.

The system of nonlinear partial differential equations in model 6 and 7 have been non-dimensionalised and then converted to a system of ordinary nonlinear differential difference equations by finite difference approximations. These equations and the other non-dimensionalised ordinary differential equations have been integrated by standard numerical techniques.

The governing equations in all the above models have been obtained from the law of conservation of mass, law of conservation of momentum and equation of state for a gas. The flow has been considered barotropic, isothermal and the friction factor has been evaluated by quasi-steady state approximation for turbulent and as well as for laminar flow conditions. The analysis has been carried out only for a step type input since it closely approximates the valve action at the inlet to the system during emergency braking conditions.

Experimental results were obtained for the case of 45, 40, 30 and 20 wagon trains on a brake rig at the brake development laboratory, Research Design and Standards Organisation, Lucknow. The theoretical results obtained from each model have been compared with experimental values and a reasonable agreement has been noted between them for most of the models.

CONTENTS

CONTENTS