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A moving model rig with a scale ratio of 1/8 for high speed train aerodynamics

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ABSTRACT

To achieve an accurate aerodynamic optimization of the outline of a high speed train and an experimental simulation of the meeting of two trains, especially in a tunnel, a train model in a moving model rig (MMR) should feature a large scale ratio and be capable of accelerating to the real Mach number. For this purpose, an MMR is developed for the acceleration, testing, and deceleration of a train model along opposite directions. To meet the railway standards of China, the distance between the centers of the two tracks is set to 625 mm for the scale ratio of 1/8. The powers of the train models originate from compressed air and the brake force from the motion of the permanent magnets relative to the motionless steel plates along the tracks. The compressed air from an air gun with an air chamber pushes a set of pistons in an accelerating tube forward. These pistons tow a trailer through a towrope, and this trailer drives the train model up to a certain speed. The initial pressure of the compressed air determines the speed of the train model, and the brake distance depends on the kinetic energy of the model and the weight of magnets on the bottom of the model. The corresponding experimental measurements are presented in this work. Two train models weighing 265 and 106 kg can be accelerated to speeds of 401 and 507 km/h, respectively, within a brake distance of 70 m. Thus, the train model with one or several cars can have a scale ratio of at least 1/8. Additional experimental results on the evolution of the pressure wave on the tunnel wall are introduced to demonstrate the repeatability of the experiment on the train model passing through the tunnel model.

1. Introduction

As trains accelerate, aerodynamic resistance and noise strength all increase. When train speed is over 300 km/h, about 80% of the train's power is used to overcome aerodynamic resistance (Schetz, 2001; Raghunathan et al., 2002). Therefore, the aerodynamic shape of high speed trains should be optimized to reduce air resistance and noise. In other instances, aerodynamic processes such as the passing of trains through tunnels, bridges, and buildings lead to sudden changes in the pressure on train surfaces. Moreover, when two trains meet in an open air environment or in a tunnel, the intricate fluctuation of pressures on the trains disturbs the smooth motion of the trains to a certain extent because of the interaction between the train aerodynamics and the propagation of the pressure wave in the tunnel (Schetz, 2001; Raghunathan et al., 2002; Tian, 2007; Wagner et al., 2014). Therefore, these aerodynamic processes deserve theoretical and experimental investigation to ensure the safety and stability of high speed trains.

A moving model rig (MMR) is usually more advantageous in experimental studies on train motion than in wind tunnel experiments. First, given the relative motion of trains on road surfaces, MMRs are highly suitable for experiments simulating actual scenes. Second, wind tunnel experiments for trains can only simulate processes involving the movement of a single train in a simple environment, such as in open air. Experimental simulations of trains passing through tunnels and buildings and over bridges can be conducted only with MMRs. Finally, meetings of trains can only be simulated with MMRs for experimental research. Therefore, this type of technology has gradually become an important experimental measurement device for the research of high speed trains. Moreover, the development and construction of MMR devices with large scale ratios and high simulation speeds are excellent bases of accurate experimental simulations, especially those on the dynamic characteristics of high speed trains.

Several MMRs for studying the dynamics of high speed trains have been constructed all over the world. In the UK, the TRAIN rig featuring a test section of 50 m can accelerate a train model with a scale ratio of 1/25 to a maximum speed of 270 km/h, with the train

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model driven by two sets of rubber catapults for two rigs (Johnson and Dalley, 2002). The German Aerospace Center employs the simulation equipment called the TSG, in which a train model is driven by a hydro-pneumatic device and passes through a tunnel or wind area at a constant speed. The speed of the model can be adjusted up to the maximum of 360 km/h. The length of its track is 60 m, and the equipment can be outfitted with a tunnel simulation device. The circulating wind tunnel can provide winds of up to 90 km/h in the direction perpendicular to the track (http://scart.dlr.de/site/test-facilities/tsg/). The scale ratio of the model with a maximum weight of 10 kg ranges from 1/100 to 1/20. At the end of the track, soft plastic balls on the ground are used to decelerate the model. With crosswind at different speeds, this experimental equipment is mainly utilized to measure the pressure wave at the inlet and outlet of the tunnel as the train model passes through with different outlines. The MMR of the Key Laboratory of Track Traffic Safety, Central South University measures 164 m in length. Two models can move along opposite directions for the simulation of two trains crossing each other. The scale ratio ranges from 1/20 to 1/16. The train model accelerates through two levels of a pulley mechanism up to a maximum speed of 500 km/h. The brake system of the device adopts a combination of several types of mechanical brake systems, including friction brake, piston brake, and brake disc, to ensure the smooth deceleration of the train model (Zhou et al., 2014). A number of devices based on the air gun principle have been built to study the characteristics of tunnel pressure wave for high speed trains (Ozawa and Maeda, 1988; Takayama et al., 1995; Sasoh et al., 1998; Demmenie et al., 1998; Doi et al., 2010; Endo et al., 2014). However, for an accurate aerodynamic simulation in the design and optimization of trains with complex outlines in the field of engineering, train models should have scale ratios larger than 1/10 and reach the same speed as that of actual trains (Peters, 1983; Schetz, 2001; Tian, 2007).

The size of a train model is known to be directly proportional to its mass and kinetic energy. Thus, powerful drive capabilities and effective brakes are requisite for MMRs with large-scale train models. The advantages, sophistication, and repeatability of MMRs are obviously determined by the principles of acceleration and deceleration of train models, as well as by the scale ratio and speed of such train models. Moreover, the aforementioned two processes depend on the driving and braking mechanisms of train models. Yang et al. (2013) successfully developed technologies for the acceleration and deceleration of small train models, whose driving power and braking force originate from the release of compressed air and the motion of magnets on the model relative to the steel plates on the ground, respectively.

In the present work, we optimize the above principles in our development of an MMR with a scale ratio of 1/8. Specifically, this work reports the principles and corresponding parameters of the proposed MMR. In this MMR, the length of the test section is 60 m, and the train models weighing 265 and 106 kg are not only accelerated to the maximum speeds of 401 and 507 km/h but also decelerated smoothly by the magnetic force within 70 m. Some experimental simulations on the passing of a train through a tunnel are reported to reveal the good repeatability of the experiments under the same initial compressed air pressure in the MMR.

2. Experimental device

The proposed MMR is established in Huai Rou District, Beijing. In the MMR, two train models along different tracks in reverse directions intersect to demonstrate the meeting of two trains, a photograph for this MMR is given in Fig. 1. The corresponding structures and working principles are shown in Fig. 2(a) and (b). To simulate these cases with a scale ratio of 1/8, the distance of the track center is set to 625 mm to represent the actual distance of a 5 m railway track in China. In this device, the length of the upper track for the train model is 264 m, and the distance between two tracks is 140 mm; for the lower track, the values for the trailer are 110 m and 100 mm, respectively. The train model and trailer are respectively restricted to the upper and lower tracks, but they are set to move freely along the tracks with the slide blocks of the model and the trailer, respectively. The vertical distance between the two tracks is 75 mm. The schematic diagram for the acceleration and deceleration of the train model is shown in Fig. 2(b). The acceleration length is 58.5 m, and the deceleration distance is 51 m for the trailer. The lengths of the acceleration and deceleration tubes for the pistons are 50 m and 48 m, respectively, and they are with the same diameter of 204 mm. An exit tube with a length of 6 m and a diameter of 204 mm is provided between the two tubes above, and 24 rectangular holes with a dimension of $160 \times 200\ \text{mm}^2$ downward are averagely distributed for the exit of compressed air.

Fig. 1. Photograph of the MMR with a scale ratio of 1/8 in Huai Ruo District, Beijing.

Initially, the end of the acceleration tube for the input of compressed air is sealed with a flange, but a small hole with a diameter of 20 mm is provided at the center of the flange for the towrope. The towrope is connected to a piston with a diameter of 203 mm in the acceleration tube and the trailer on the lower track, as shown in Fig. 2(a) and (b). Another piston is located between the stationary flange and the moving piston. The second piston can freely move along the towrope in the tubes because the towrope passes through the hole at the center of this piston. In this device, the length of the towrope is equal to that of the lower track and is shorter than the sum of the lengths of the acceleration tube, exit tube, and deceleration tube. This setting ensures that the first piston stops in the deceleration tube as the trailer reaches the end of the lower track.

The compressed air for driving the pistons comes from an air gun with a gas chamber of $3.0\ \text{m}^3$ and its schematic diagram is shown in Fig. 3(a). The cross section of the piston in the stainless steel cylinder is four times that of the plug at the exit of the gas chamber. To operate this air gun safely, three solenoid valves are used in controlling the entry of the compressed air into the chamber, the connection and isolation of the regions on the two sides of the piston in the cylinder, and the sudden release of the compressed air stored in the cylinder.

The process for the storage of the compressed air is as follows. The No. 2 solenoid valve is first opened to connect the regions on the two sides of the piston and thereby cause the plug to shut down the air chamber as the compressed air from the No. 1 solenoid valve enters the cylinder and drives the piston. As a result of the pressure difference of both sides of the plug, the plug is sealed for the chamber, and the compressed air is stored and increased as needed to achieve the desired speed of the train model. After the