Design Evaluation and Material Optimization of a Train Brake

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Abstract: *A moving train contains energy, known as kinetic energy, which needs to be removed from the train in order to cause it to stop. The simplest way of doing this is to convert the energy into heat. The conversion is usually done by applying a contact material to the rotating wheels or to discs attached to the axles. The material creates friction and converts the kinetic energy into heat. The wheels slow down and eventually the train stops. The material used for braking is normally in the form of a block or pad. The vast majority of the world's trains are equipped with braking systems which use compressed air as the force to push blocks on to wheels or pads on to discs. These systems are known as "air brakes" or "pneumatic brakes". The existing air brake system of Railway coach has the following drawbacks due to excessive brake force on the brake blocks - thermal cracks on wheel tread, brake binding and reduced life of brake block. The aim of the project is to overcome the above said drawbacks by reducing the effective brake force on the brake blocks without affecting the existing designed (Braking Function) requirements. To validate the strength of train brake, Structural and Modal analysis are to be done on the train brake. In structural analysis, ultimate stress limit for the design is found and in modal analysis, mode shapes of the train brake for number of modes can be analyzed. The analysis is done by applying two different materials Cast Iron and High Carbon Steel for train brake.*

Keywords: *Stress analysis, model analysis, train brake, cast iron, high carbon steel*

1. Introduction

The vast majority of the world's trains are equipped with braking systems which use compressed air as the force to push blocks on to wheels or pads on to discs. These systems are known as "air brakes" or "pneumatic brakes". The compressed air is transmitted along the train through a "brake pipe". Changing the level of air pressure in the pipe causes a change in the state of the brake on each vehicle. It can apply the brake, release it or hold it "on" after a partial application. The system is in widespread use throughout the world.

In the air brake's simplest form, called the *straight air system*, compressed air pushes on a piston in a cylinder. The piston is connected through mechanical linkage to brake shoes that can rub on the train wheels, using the resulting friction to slow the train. The mechanical linkage can become quite elaborate, as it evenly distributes force from one pressurized air cylinder to 8 or 12 wheels.

The pressurized air comes from an air compressor in the locomotive and is sent from car to car by a *train line* made up of pipes beneath each car and hoses between cars. The principal problem with the straight air braking system is that any separation between hoses and pipes causes loss of air pressure and hence the loss of the force applying the brakes. This deficiency could easily cause a runaway train. Straight air brakes are still used on locomotives, although as a dual circuit system, usually with each bogie (truck) having its own circuit.

In order to design a system without the shortcomings of the straight air system, Westinghouse invented a system wherein each piece of railroad rolling stock was equipped with an air reservoir and a *triple valve*, also known as a *control valve*.

1.1 Brake Application

The driver has placed the brake valve in the "Application" position. This causes air pressure in the brake pipe to escape. The loss of pressure is detected by the slide valve in the triple valve. Because the pressure on one side (the brake pipe side) of the valve has fallen, the auxiliary reservoir pressure on the other side has pushed the valve (towards the right) so that the feed groove over the valve is closed. The connection between the brake cylinder and the exhaust underneath the slide valve has also been closed. At the same time a connection between the auxiliary reservoir and the brake cylinder has been opened. Auxiliary reservoir air now feeds through into the brake cylinder. The air pressure forces the piston to move against the spring pressure and causes the brake blocks to be applied to the wheels. Air will continue to pass from the auxiliary reservoir to the brake cylinder until the pressure in both is equal. This is the maximum pressure the brake cylinder will obtain and is equivalent to a full application. To get a full application with a reasonable volume of air, the volume of the brake cylinder is usually about 40% of that of the auxiliary reservoir.

2. Design of Train Brake

Fast expanding industrialization of country needs fast movement of higher freight and passenger railway traffic coupled with safety of men and material. Air brake system plays an important role in running of trains.

The existing air brake system of Railway coach has the following draw backs due to excessive brake force on the brake blocks.

a. Thermal Cracks on wheel tread.

b. Brake binding.

c. Reduce life of brake blocks.

A modification is made in this project work to overcome the above said troubles by reducing the minimum effective brake force on the brake blocks without affecting- the existing designed(braking function) requirements(i.e. 905 meters braking distance at 110kmph coach speed)by RDSO on trial basis.

The suggested modification is to change the horizontal leverage ratio in the horizontal lever. The horizontal lever transfers braking force from brake cylinder to the brake rigging arrangement of Air brake system. By changing the horizontal leverage ratio, the mechanical advantage of the brake system can be reduced which in turn reduces the minimum effective brake force on the brake blocks.

The procedure of implementation of modification and brake force calculation are discussed in this research

2.1 Air Brake System

In Air brake system compressed air is used for operating the brake system, the locomotive compressor charges continuously the feed pipe and brake pipe throughout the length of the train. The feed pipe is connected to the auxiliary reservoir and the brake pipe is connected to the brake cylinder through the distributor valve. Brake application takes place by dropping the air pressure in the brake pipe. Brake releasing by recharging brake pipe pressure to the required valve (5kg/cm^2) through the driver valve. The Railway administration introduced highly efficient and reliable air brake system over heavy freight wagons and coaches. Thus conventional vacuum brake on the rolling stock has been replaced which has several limitations.

2.2 Limitations of vacuum Brake system

a. Speed limitations due to longer braking distance.

b. Brakes releasing time is more.

2.3 Limitations on train loads and lengths.

a. Vacuum in the last vehicle is not maintained as desired.

b. Lesser braking force generation by brake cylinder.

c. Higher maintenance cost.

Air brake system has the following major advantages over vacuum brake system.

Advantages of air brake system:

a. Speed of the train increased.

b. Load of wagon/coach increased.

c. Shorter braking distance

2.4 Brake Force Calculations

2.4.1 Standard Designed values

According to RDSO (Research and Development Standards Organization), Lucknow, the following are standard designed values for Railway air brake system.

Brake cylinder diameter: 355.6 mm (14 inches)

Effective piston force of brake cylinder: 3.6 tons.

Number of brake cylinders per coach: 2

Number of brake bogie levers per coach: 4.

Mechanical efficiency of brake rigging: 0.9.

Brake rigging ratio: 0.9.

Number of brake blocks per one coach: 16

2.4.2 Air brake Details

Mechanical advantage of bogie:

Bogie leverage ratio X no.of bogie levers

Mechanical advantage of complete brake system:

Mechanical advantage of bogie X Horizontal leverage ratio

Theoretical brake force:

Mechanical advantage of complete brake

system X Effective piston force X No.of

Brake cylinders per coach

Minimum effective brake force:

Theoretical brake force X Brake rigging ratio

X Mechanical efficiency of brake rigging.

2.5 Trouble with Existing System

Trouble with existing system is that the excessive brake force development at the brake blocks with the existing air brake system which results in

a. Thermal cracks on wheel tread.

b. Brake binding.

c. Reduced life of the brake blocks.

2.6 Suggestions Modification

The suggested modification is to reduce the excessive brake force on brake by changing the existing horizontal leverage ratio 420: 280 to modified value 372: 328 which in turn reduces the excessive brake force

3. Results and Discussions

As per the research conducted, stress and model analysis results were captured with a structured mesh throughout the domain for the present design of a train brake.

Figure1. *Train Brake model considered for the research*

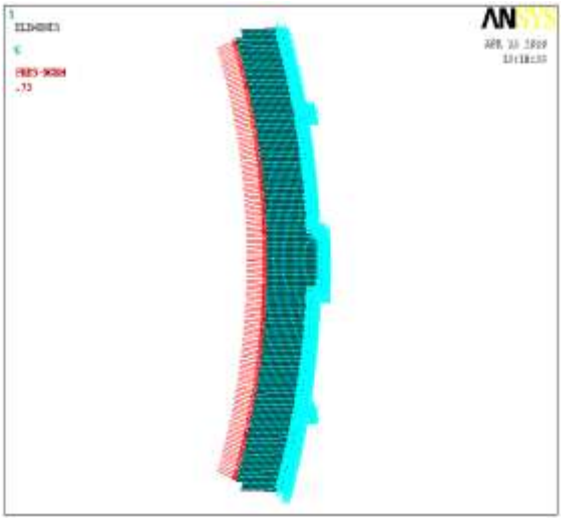

Figure2. *Structured Mesh performed for the present design*

From the above mesh image, it can be observed that a structured mesh throughout the domain is considered for increasing the accuracy of the results. The present mesh is considered for both the brake forces considered in the research.

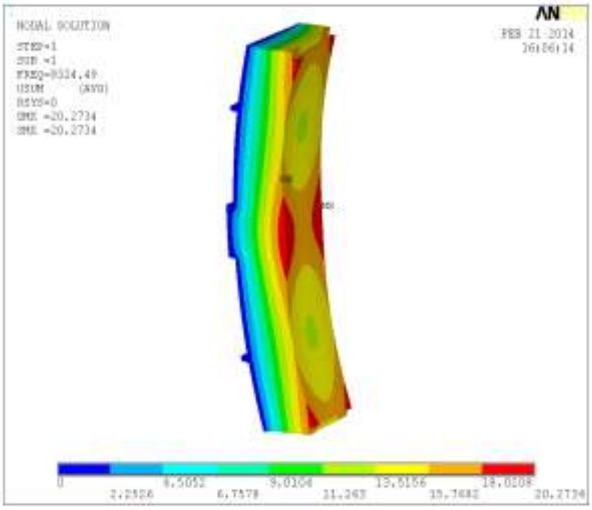

Figure 3. *Cast iron Model analysis*

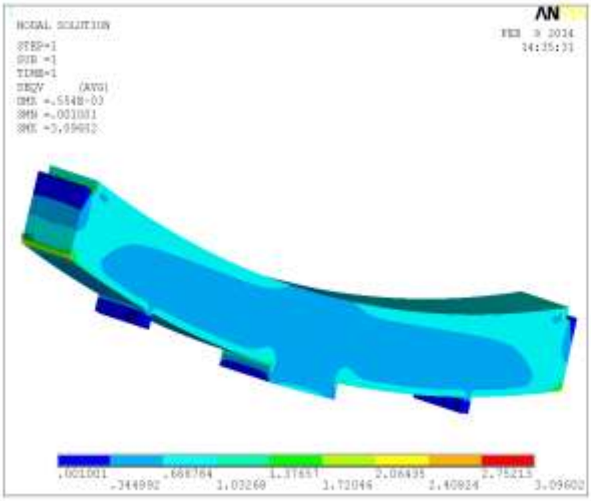

Figure 4. *Cast Iron Stress Analysis*

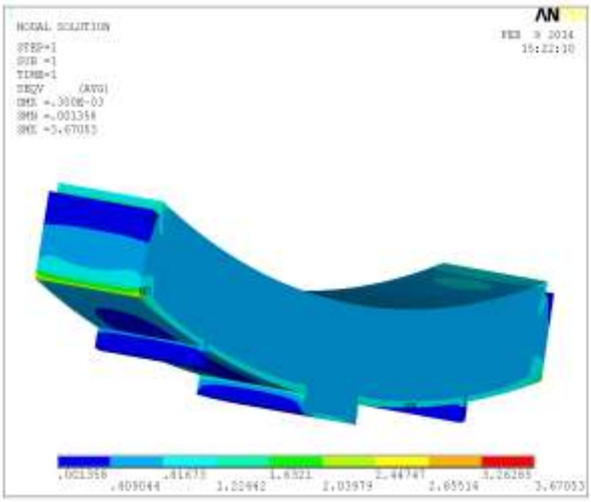

Figure 5. *High Carbon Steel Stress analysis*

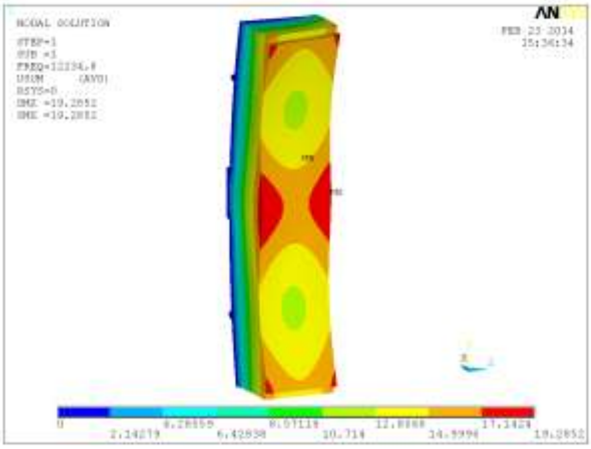

Figure 6. *High Carbon Steel Model analysis*

Above images illustrates the stress and model analysis plots for the existing and modified train brake system. From the plots illustrated above, conclusions were made for the present research

Table 1. *Cast Iron by applying 2.187 tons*

	Results	**Permissible**
DISPLACEMENT (mm)	0.554e-3	
VONMISES STRESS (N/mm^2)	3.09	520

Table 2. *Cast Iron by applying 1.653 tons*

	Results	**Permissible**
DISPLACEMENT (mm)	$0.418e^{-3}$	
VONMISES STRESS (N/mm^2)	2.33	520

Table 3. *High Carbon Steel by applying 2.187 tons*

	Results	**Permissible**
DISPLACEMENT (mm)	$0.300e^{-3}$	
VONMISES STRESS (N/mm^2)	3.67	295

Table 4. *High Carbon Steel by applying 1.653 tons*

	Results	**Permissible**
DISPLACEMENT (mm)	$0.22e^{-3}$	
VONMISES STRESS (N/mm^2)	2.765	295

4. CONCLUSION

According to the existing air brake system of Railway coach the brake force applied per one brake block is 2.187tons. The following drawbacks due to existing brake force on the brake blocks - thermal cracks on wheel tread, brake binding and reduced life of brake block. A modification is done in the project to overcome the above said troubles by reducing the minimum effective brake force without affecting the existing designed requirements. After modification, the brake force applied per one brake block is 1.653tons.The analysis is done for two forces and by using two materials Cast Iron and High Carbon Steel. The maximum stress induced in the brake block by the application of modified brake force (1.653 N) is 2.765 N/mm^2 which is less as compared with stress induced in the brake block by the existing brake force (2.187N) 3.67 N/mm^2. With the application of modified minimum brake force, the brake block is safe. Hence the modification carried out in this project work is justified. By comparing the results for both materials, stress obtained is less for High Carbon Steel is less when compared with Cast Iron. Therefore, from the present research it can be concluded that using High Carbon Steel is best for train brake.

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