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Methods to Reduce Rail Temperature Changes

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Summary

Transportation Technology Center, Inc. (TTCI), in conjunction with PCM Thermal Solutions, Inc., has been researching ways to mitigate the effects of high temperatures on railway track through three specific technologies: phase change materials, heat pipes, and radiant reflective coatings. Results from analytical and numerical computer-based modeling estimate these temperature mitigation techniques can decrease the maximum rail temperatures between 10° F and 20° F in the most extreme, base-case circumstances.

Track structures and components in the railway industry face a large variety of weather and temperature conditions. Specifically, high temperatures and solar radiation are problematic as they tend to force rail temperature to escalate over the rail's neutral (zero-stress) temperature. Correspondingly high compressive forces due to increased rail temperature make the track structure more susceptible to alignment deviations and longitudinal buckling failures. A lower range of rail temperatures will result in lower rail longitudinal forces, which should lead to fewer track buckles and tensile rail failures. Additionally, the lower range of rail temperatures should result in less track lateral movement.

Reducing maximum rail temperature offers railroads significant benefits in reducing longitudinal forces in rails. Currently, rails are installed at high temperatures to assure that compressive longitudinal forces are minimized during the warmest portions of the year. This practice can lead to high tensile forces in rail during cold weather. By limiting rail maximum temperatures, the railway can lower rail installation temperatures and have the added benefit of limiting "blanket" speed restrictions for lines during the hottest times of the year.

It is envisioned that methods to reduce rail temperature changes described in this document could become niche applications that supplement conventional rail longitudinal stress management techniques in the most challenging weather and operating environments. However, the economic benefits of these technologies have not been evaluated.

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INTRODUCTION

Railway track structure is exposed to a variety of conditions found throughout North America and abroad. In particular, high ambient temperatures in conjunction with solar radiation cause thermal expansion within rail steel. This in turn leads to high compression forces in the rail making the track more susceptible to structural failure, compromising track integrity and safety. Transportation Technology Center, Inc. (TTCI), in conjunction with PCM Thermal Solutions, Inc., has been researching ways to mitigate the effects of high temperatures on railway systems.

BACKGROUND

The railway industry has sought ways to mitigate negative thermal effects on rails. Greater control of rail temperatures can help prevent the build-up of longitudinal stress in the rail. Compressive stresses from radiation and high air temperatures tend to cause buckling failures, while cooler temperatures put the rail in tension leading to pull-aparts and potentially more broken rails. Additionally, rails with temperature mitigation would have less need for blanket speed restrictions.

There are several potential mitigating technologies, both active and passive, that can cool peak rail temperatures during summer operations, and/or maintain optimal rail temperatures in winter months. Active technologies require the input of mechanical or electric power, making them cumbersome, and difficult to install and maintain. Passive technologies could provide a simpler, but still effective way to manage temperature and radiation effects with lower cost and little to no maintenance. These passive technologies have demonstrated their effectiveness in cooling applications in other industries.

High rail temperatures can negatively affect revenue service by creating situations in which a railway line must “blanket” restrict their speeds. Depending on the laying temperature for the continuously welded rail, these restrictions can span entire lines if the neutral temperature is low enough. Generally, these restrictions are more commonly seen in locations where the range of temperatures over the year is wider. Temperature effects are not limited to warmer seasons. Cooler months see the rail temperature drop below the neutral temperature; thus putting the track into tension. Broken rails can be a side effect of a track experiencing high tensile forces.

The ultimate solution for managing rail thermal stresses is a real-time measurement system that can be used during on-board track inspections. Without real-time measurement of rail forces the railroads conservatively assume that stress-free rail temperature or Rail Neutral Temperature (RNT) is as low as the mean ambient temperature for a location. This can result in additional track inspections, limited maintenance activities, and possible limited train speeds when the current ambient temperature reaches a threshold above mean ambient temperature.

While the industry continues to work diligently on real-time measurement of RNT, other means of managing and controlling rail thermal stresses are being explored. One such technique is to limit the range of rail temperatures that may be expected during the year. Thus, TTCI and PCM Thermal Solutions, Inc. are exploring the methods discussed in this *Technology Digest*. The analytical work described suggests that a reduction of maximum temperatures of 10°F to 20°F may be possible. The economic benefits in reduced rail stress, related accidents, and reduced associated countermeasures make this technology worthy of exploration.

PROPOSED TECHNOLOGIES

It is well-known in the industry that steel rails contract and expand in response to temperature fluctuations. PCM Thermal Solutions, Inc. has conducted research to demonstrate three potential, passive technologies for diminishing adverse temperature effects on rails. These three technologies are described below.[1-3]

- *Phase change material (PCM).* PCMs take advantage of the latent heat released or absorbed when it undergoes a change of phase. During the phase change process, the material will stay at a relatively consistent temperature until it absorbs the maximum amount of latent heat. This allows PCMs to maintain components at constant temperatures throughout their heating cycles. Cyclic heating cycles found between days and nights provide PCMs with the necessary time to discharge their heat between peak temperatures. A wide variety of PCMs are available for use in rail cooling applications, making them adaptable for various thermal loading environments.
- *Heat pipes.* Heat pipes use convective cycling across a temperature gradient to dissipate thermal loads. A heat pipe essentially transfers thermal loads from the rail into a heat sink or thermal reservoir. Ideally, this would be the ground in railway applications. Heat pipes also have the added benefit of potentially sustaining higher rail temperatures during winter month by drawing heat from the ground
- *Solar reflectivity coatings.* The main principle behind these coatings would be to increase rail resistance to solar radiation by increasing the rail

reflectivity and reducing its absorption of radiation. This particular technology has been studied previously by TTCI.

EVALUATION OF TECHNOLOGIES

Analytical and numerical analysis has been developed for estimating the effect of these various technologies on improving thermal performance of the rail. This report will focus on PCM numerical simulations.

It is expected that numerical simulations might not be sufficient in determining that PCM or heat pipes can indeed enhance thermal performance of various rail temperature mitigation and control technologies However, the main reason for conducting three-dimensional thermal simulations is to observe and confirm if thermal distribution is sufficiently uniform to produce uneven excessive thermal rail expansion.

Modeling was conducted using a computational fluid dynamic (CFD) software package. Accurate model geometry was sacrificed for computation time; therefore, the rail was represented as a collection of regular, rectangular extrusions in the model.

Environmental conditions were chosen based on some of the worst-case-scenario conditions for maximum temperature that a rail is likely to be subjected to in revenue service. The chosen location was Phoenix, Arizona, at approximately 32° N Latitude during a typical summer day (July 21, 2016). Figure 1 shows the air temperature history for this location on this day.

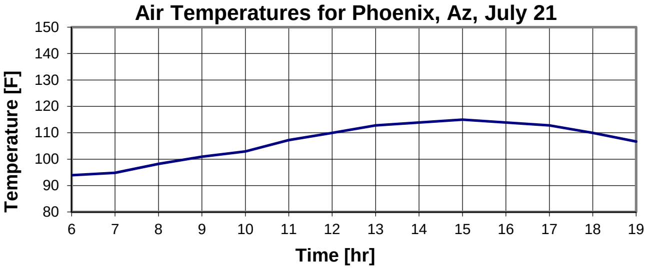

Figure 1. Air Temperatures for Phoenix, AZ in July

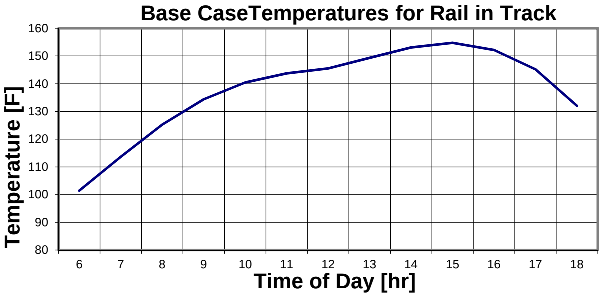

Figure 2. Rail Temperature Predictions in July

A baseline control model was developed to provide temperature profiles for the midpoint of the rail without any mitigation technology. Peak temperature is 144°F at around 5:00 p.m., as shown in Figure 2.

All technologies were tested for the temperature profile taking place from 6:00 a.m. to 7:00 p.m. (13 hours).

Phase Change Materials

The first technology implemented into the model was the phase change material, which was modeled in two configurations: PCMa and PCMb. PCMa consists of two separate containers attached to the web of the rail on opposite sides.

Both containers measure 14mm×50mm×400mm and contain sodium acetate trihydrate as its phase change material. The PCMb configuration uses two containers as well, but extends them along the entire length of the web. It too uses sodium acetate trihydrate. The PCMb configuration uses 4.6 pounds of the PCM; whereas PCMa uses 1.8 pounds. Figure 3 shows the results for the PCM design configurations. Those marked "No PCM" are the base case for their test's respective results. As can be seen in the figure, PCMb is much more efficient at transferring heat from the rail. In this scenario, the maximum rail temperature was reduced by perhaps 12°F.

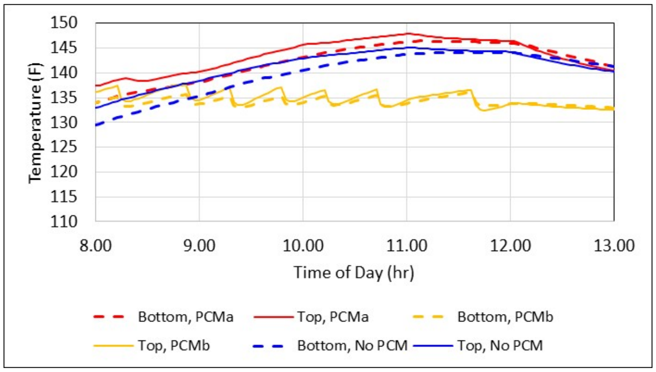

Figure 3. Rail Temperature Predictions for PCM Cases

Heat Pipes

The model was adapted to illustrate the effect from two different heat pipe configurations. Configuration 1 (HP1) uses a single heat pipe at the center of the rail with a capacity of 50 W (170 Btu/hr.) connected to a ground well at 58°F. Configuration 2 (HP2) simply adds an additional, identical heat pipe to the rail at quarter points from each edge of the rail. Results for running the base model with the integrated heat pipe configurations are shown below in Figure 4. Histories labeled "No Heat Pipe" are the base cases for each respective analysis. Reductions in maximum rail temperatures of up to 18°F were predicted for the modelled scenario.

As with the PCM application, the heat pipes also moderate the rate of temperature increase.

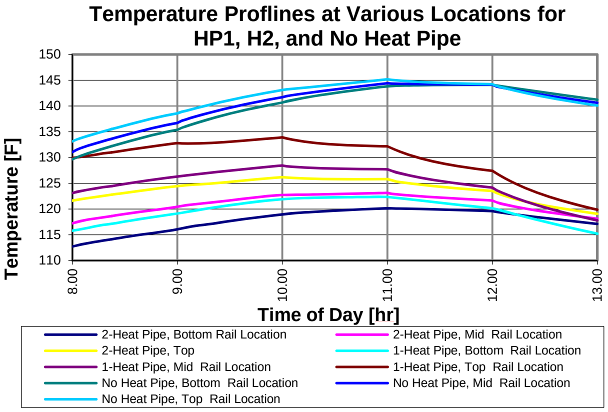

Figure 4. Rail Temperature Predictions for Heat Pipe Cases

Reflective Coatings

The final suggested technology for high rail temperature mitigation are reflective coatings. Unlike the previous two technologies, no numerical modeling was conducted for reflective coatings. Instead, only thermal analysis was conducted using various alpha values of reflectivity. As seen in Figure 5, these values are within reason to what can be achieved by the proposed coat systems. Alpha value 0.45 is considered the base case scenario for this analysis. As Figure 5 shows, the maximum rail temperature is predicted to be 20°F lower with a very reflective coating. Note that the shape of the temperature – time curves are very similar for all levels of rail reflectivity analyzed.

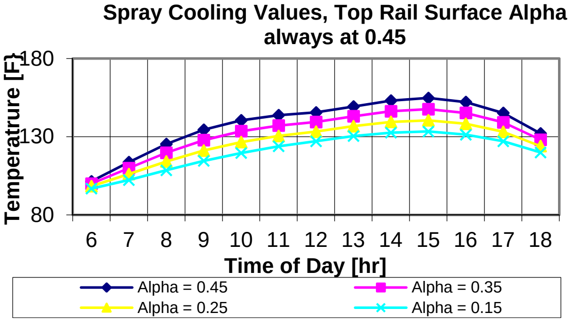

Figure 5. Rail Temperature Predictions for Reflective Coatings Cases

CONCLUSION

Both analytical and numerical calculations were carried out on the various proposed passive cooling technologies designed to mitigate and control rail temperatures during summer months. The following rail temperature mitigation technologies were investigated:

1. Phase change materials: Designed to absorb heat during the hottest hours of the afternoon.
2. Heat pipes: Used to transfer heat from the rails to the cooler ground during the hottest hours of the afternoon.
3. Coatings: Low-solar absorptivity paints that reduce the amount of solar heat absorbed by the rails during the hottest hours of the day.

Analytical and numerical calculations demonstrated that the implementation of each technology can reduce rail temperatures during the hottest periods of the day during the summer months by 10 °F to 20 °F.

RECOMMENDATIONS

This feasibility study demonstrated that the three technologies, on paper, can potentially mitigate the rail temperatures during the hottest hours of the afternoon during the summer.

Similar studies could be conducted for winter operations to determine if rail temperatures can remain at sufficiently high levels to keep rails free of snow and ice during the coldest hours of the day. Heat pipes, in particular, have the potential to keep the rail at not just a cooler temperature during the summer, but generally at a more consistent temperature year-round.

Further, it would be desirable to carry out demonstration/testing projects of the various technologies in actual field conditions to corroborate the results of this project. Moreover, laboratory testing of a small rail sample under the various technologies can also be carried out using facilities similar to those used by the telecom industry in the testing of outdoor enclosures.

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