The search for beneficial new technologies for rail transportation - TTCI R&D - Association of American Railroads' Technology Scanning Program

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AAR's Technology Scanning Program continues to find and provide innovative technologies.

Twenty years ago, the Association of American Railroads' Research and Test Department envisioned having a forum to introduce new technology and technologists to the railroad industry. That vision became a reality soon after when the AAR began its Technology Scanning Program.

With a mission of ensuring a continued infusion of new ideas and technologies into railroad transportation engineering through two avenues, human resources and research deliverables, the program has brought about innovative changes in the way railways do their business. Four key elements of the mission are to:

* support research on important railroad topics at leading North American engineering universities;

* raise the visibility of rail transportation topics among faculty and students at these universities;

* provide a resource for specialized technical expertise for the railroad industry;

* encourage student interest in careers in rail transportation and engineering.

Unlike AAR's Strategic Research Initiatives Program, which is aimed at solving today's problems and providing the best economic return on AAR's investment in research and development, AAR's Technology Scanning Program provides the industry a longer-term view of potential applications of new technologies.

In 1982, the AAR initiated the Technology Scanning Program with three universities: University of Illinois at Urbana-Champaign, Massachusetts Institute of Technology and Carnegie-Mellon. Since 1982, Carnegie-Mellon was replaced by the Texas Transportation Institute at Texas A&M University. As an example of how the program functions, this article focuses on work being done at UIUC.

Modeling of thermite welds

Recent work at the UIUC on the external geometry of thermite welds has demonstrated several improvements that show great promise in substantially extending their life in track. The next step under way is to investigate the internal improvements in weld quality that are also important to their longevity in service.

Internal defects such as shrinkage cavities, microporosity, inclusions and a coarse dendrite structure affect the mechanical properties of welds, particularly their fracture toughness and fatigue performance. The formation of these defects occurs during solidification and is thought to be due to thermal conditions. Finite element methods are being used to calculate the temperature effects throughout the thermite welding process to better understand how to avoid the formation of defects.

Thermite welding involves many complex physical and chemical processes. Experimental study would be expensive and time consuming. However, thanks to the advance of numerical modeling techniques and computer power in recent years, it is possible to simulate the weld temperature evolution by modeling the fundamental physical phenomena, such as heat transfer, solidification and fluid flow, during thermite welding.

UIUC investigator Prof. Frederick Lawrence and his students are developing a computer model to simulate various welding conditions and to calculate the temperature patterns during the welding process and the thermal conditions leading to weld defects. A number of processing parameters are being considered, including: ambient temperature, preheating time, preheating temperature distributions, tapping time and pouring temperature. The model is still under development and being refined by comparison with laboratory experiments, but some of the preliminary results are as follows:

* Increasing the preheat time from two to seven minutes increases the average melt-back width by about 10 percent, thereby helping to prevent "cold laps," an important cause of weld cracking and failure.

* Sufficiently high weld pouring temperature overwhelms any prior thermal conditioning resulting from preheating or tapping time delay. A 400-degree C difference in pouring temperature can alter the melt-back width more than 30 percent.

* Pouring temperatures higher than 2,200 degrees C are unlikely to result in any shrinkage cavity in the rail web. However, lower pouring temperature can create such cavities that are another source of origination for fatigue cracks that can shorten weld life.

* The solidification rate is much slower in the rail head. Consequently, this condition may favor the formation of microporosity in the rail head.

Measurements of rail stress

A long-standing need of the railroad industry has been the ability to measure contained stress in rail. The widespread adoption of continuously-welded rail has made the topic even more important.

High compressive loads in rail can lead to track buckling and high tensile loads can cause broken rails. Both of these conditions may be the cause of serious derailments; at a minimum, they interfere with operations and service quality.

Although rail stress can be inferred by comparing ambient temperature with the neutral temperature, this drifts over time due to a variety of factors. Railroad engineering personnel may be uncertain as to the stress condition of the rail. Current methods for assessing stress are cumbersome, expensive and often inaccurate. Thus, there continues to be interest in possible new technologies that could lead to a practical, portable system for field measurement of rail stress.

Professor Richard Weaver of the UIUC Theoretical and Applied Mechanics Department specializes in studies of material vibration phenomenon. It is well known that vibration is affected by stress. Compressive loads lower the free vibration frequencies of a bending beam, such as a rail, and tensile loads increase them. However, previous attempts to use this to measure stress in rail have not succeeded because other parameters, such as tie spacing and fastener stiffness, have a greater impact on vibration frequencies, and these effects were not properly controlled or accounted. A measurement technique that does account for these effects might succeed. Given the importance of the rail stress problem, Professor Weaver, with support from the AAR and the TRB, is investigating this possibility.

Two approaches are being evaluated:

* Using clamps to isolate a short span of the rail and minimize its sensitivity to fasteners, together with conventional vibration testing to evaluate the free vibration frequency of the isolated section.

* Introducing a scanned laser vibrometer measurement of waves into the rail at specified frequency, whose wavelengths depend on stress, but are independent of fasteners.

Both approaches use numerical simulations such as finite element modeling of rail vibrations to develop design guidelines for laboratory and field tests of the proposed methods. The analytical results to date indicate that although the first method might work, the size and strength of the requisite clamps is so large that it is unlikely to be feasible. Consequently, the primary focus of the current research is on the second method using induced vibration and laser vibrometry.

The basic technique is to introduce a low-energy vibration of a known frequency into the rail, and then monitor its response at various locations along the isolated section using a laser vibrometer. The results can be analyzed using algorithms developed by Weaver and his students. A section of rail provided by the CN/IC has been set up in Talbot Laboratory on the UIUC campus. Testing is under way. Besides determining if the method can provide accurate measurements of stress, the research also involves understanding the requirements and practicality for field applications. The method requires that a short section of rail be isolated from all contact with fasteners and anchors.

Preliminary results indicate that the minimum span of rail that needs to be isolated is less than eight feet and that the isolation from the fasteners and anchors need only be about 1/16 of an inch or less. Both of these conditions should be achievable in the field. Other questions involving the requisite accuracy needed for rail shape, modulus and vibration measurements are also being investigated.

Although both of these projects show great promise, it is too soon to tell if either will succeed, first in achieving their intended result and, second, in being adapted for practical use by the railroad industry. Only further research, testing and development can provide the answer. These are precisely the criteria that make them ideal as Technology Scanning projects.

The tremendous growth in technology in an ever-widening variety of engineering fields makes it more difficult than ever for railroads to know from what corner the next useful innovation will come. This is where the AAR's Technology Scanning Program comes in and is precisely the role envisioned by the AAR when it was launched two decades ago. In the ensuing 20 years, industry consolidation and the attendant reduction in railroad research personnel, continued emphasis on greater network efficiency, and the demand for higher levels of performance to improve service quality and gain market share all make the search for beneficial new technologies for rail transportation more important than ever.

The AAR is the largest single source of support and provides the critical mass necessary for the continued viability of the Technology Scanning Program. The objectives of the Technology Scanning Program are to:

* ensure that the industry maintains access and exposure to relevant, new technologies;

* facilitate the process of identifying and evaluating these technologies for railroad applications;

* encourage the development and transfer of expertise into useful applications for the rail industry;

* leverage industry resources through cooperative research projects;

* establish partnerships and alliances; e.g.,
  - Academic institutions: University of Illinois at Urbana-Champaign, Texas Transportation Institute at-Texas A&M University and Massachusetts Institute of Technology
  - Foreign railway researchers: WEC / UIC
  - International rail associations: International Heavy Haul Association
  - Professional scientific and technical associations and societies: Transportation Research Board of the National Research Council

Some of the current AAR-supported projects under way for the Technology Scanning Program are:

* Machine-vision for remote, automated railcar health analysis.

* Railroad tank car safety and hazardous materials risk analysis.

* Railcar truck rotational friction and dynamic interaction.

* Fiber optical system for force measurement and detection of truck hunting (with TRB).

* Improved fatigue-resistance and reliability of thermite rail welds (with TRB).

* Vibration techniques for field measurement of rail stress (with TRB).

* Advanced algorithms for precise GPS monitoring of track and rail position (with TRB).

* Ultrasonic techniques for detection of broken rails.

* Analysis of wheel/rail contact mechanics under high-adhesion conditions.

* Evaluation and analysis of new rail steels (with FRA).

* Environmental fate and preservative enhancement of creosote in railroad ties.

* Analysis of dynamic train load and seismically-induced instability of railroad subgrade (with BNSF).

* Grainger Engineering Library railroad engineering information search and retrieval system.

The laboratory at the University of Illinois became the largest and most prolific in the program because of its many amenities:

* Familiarity with the railroad industry--Illinois has more than a century-long history of association with the railroad industry and the AAR.

* Breadth of expertise--Illinois is one of the leading engineering research universities in North America, with breadth and depth in nearly all branches of science and engineering.

* Program Leadership--Professor Ernest Barenberg, who served as the lab's first director from 1982 through 1998, provided dynamic leadership. He was adept at matching technologies to potential applications in the railroad industry.

The UIUC railroad engineering research program includes a broad base of support from AAR, Federal Railroad Administration, Transportation Research Board, National Science Foundation, Illinois Department of Transportation, individual railroads and railway suppliers in areas ranging from materials to the engineering systems.

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