Development of Hot Box & Hot Wheel Detector

*** P.Butani & ** Dr. Sanjay Gupta**

*** P.Butani, Director Research (Mechanical), RDSO &**
**** Dr. Sanjay Gupta, Chief Scientific Officer, IIT, Kanpur**

Article submitted for the IRSME site by
Shri P.Butani, Director Research (Mechanical), RDSO

An intelligent infrared sensing system for detecting hot box due to bearing failure, hot wheels due to brake binding and cold wheels due to ineffective brakes can be a useful tool in the hands of maintenance staff and can contribute to the safety and reliability in train operations.

Background:

Hot box occurs when inadequate wheel bearing lubrication or mechanical flaws cause an increase in temperature. If undetected, the bearing temperature can continue to rise until there is a bearing "burn-off" which can cause journal breakage resulting in derailment. Another problem is brake binding, due to which the temperature of wheel tread rises. This can lead to skidded wheels, metal deposition on wheel tread causing wheel irregularity and other safety problems. Also, a wheel with temperature lower than the average is a case of ineffective brakes. A detection system is therefore required to be developed to sense abnormal temperatures of axle boxes and wheels on a running train and communicate with central control for corrective action.

Introduction:

Development of a wayside system to detect Hot Boxes & Hot Wheels has been taken up under Technology Mission for Railway Safety with IIT, Kanpur. The system detects Axle-boxes running hot due to bearing failure and wheels having abnormally high temperatures due to brake-binding.It can also detect vehicles with ineffective brakes by detecting cold wheels. The system uses infra-red sensors having fast response time and can reliably measure temperatures of axle boxes & wheels of a train travelling upto 200kmph.

The main problem which delayed the development of automated systems for hot box and hot wheel detection is the need for very rapid measurement. For example, a box which is typically 220mm wide, when travelling at 200kph will cross a point in 3.96ms. To get the temperature profile, at least ten measurements have to be made during this time interval. The alarm temperature for a hot box is around 80-90℃. Such fast measurements at these low temperatures are a tall order.

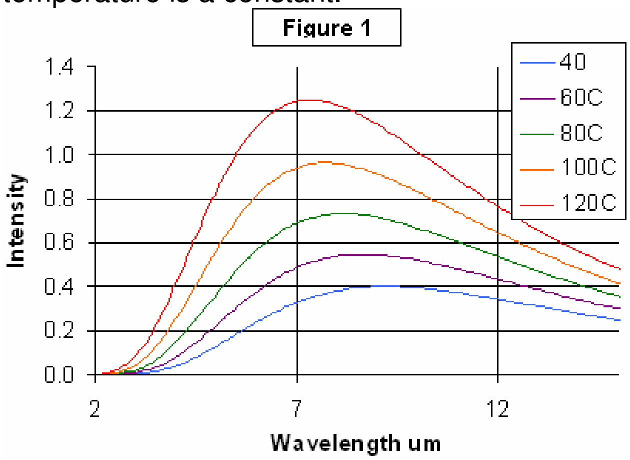
The position in the case of hot wheel is somewhat better. While the length available for measurement is only marginally more than for the 'box' (~280mm as against ~220mm) the alarm temperatures are far higher (>200℃). Such elevated temperatures pose far less of a technological challenge than the lower temperatures in the case of a box. Thus any sensors developed for the box can also be used for the wheel, with possibly some attenuation of the signal.

Technical Background:

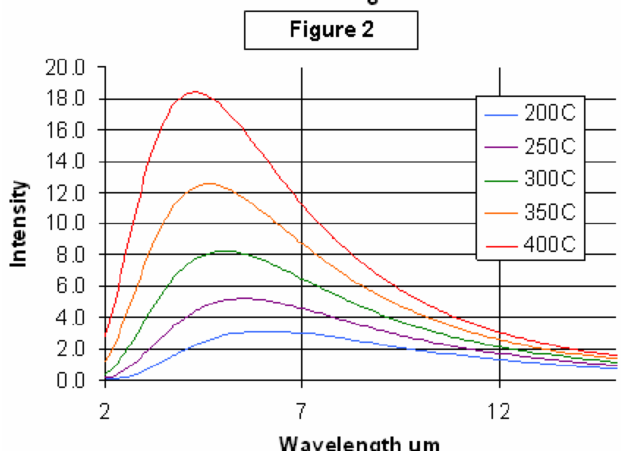
Radiation for a Blackbody is governed by the Planck's Equation:-

$$f(\lambda) = \frac{8\pi hc\lambda^{-5}}{e^{\frac{-hc}{\lambda kT}} - 1}$$

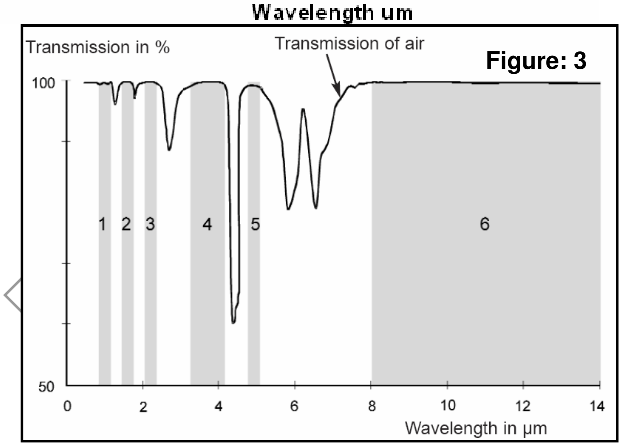
There is also a related law known as the Wien's law, which states that $\lambda_{max} T = const.$ i.e., the product of the wavelength of maximum emission and the temperature is a constant.



The black body radiation patterns for the temperature range relevant to the bearing temperature are shown in Fig. 1. It can be seen that the peak position shifts from ~9µm to ~7µm as the temperature increases from 40C (313K) to 120C (393K). Also, there is not much energy content below about 2µm.



Similarly the patterns for a higher temperature range relevant to the hot wheel measurements is shown in Figure 2. Here as expected there is significant energy content below 2µm and the peak wavelength is still lower.



However, it is not possible to work at all wavelengths with impunity. Atmospheric absorption (primarily CO_2 and water vapour) limits the working to certain well defined bands. The commonly used bands are shown in Fig.3 (source Impac) For the temperature range of interest the 3-5µm band is the most preferred.

Unlike bolometric sensors, photoconductive and photovoltaic sensors are tailored to the wavelength range of interest.

Infrared Sensors:

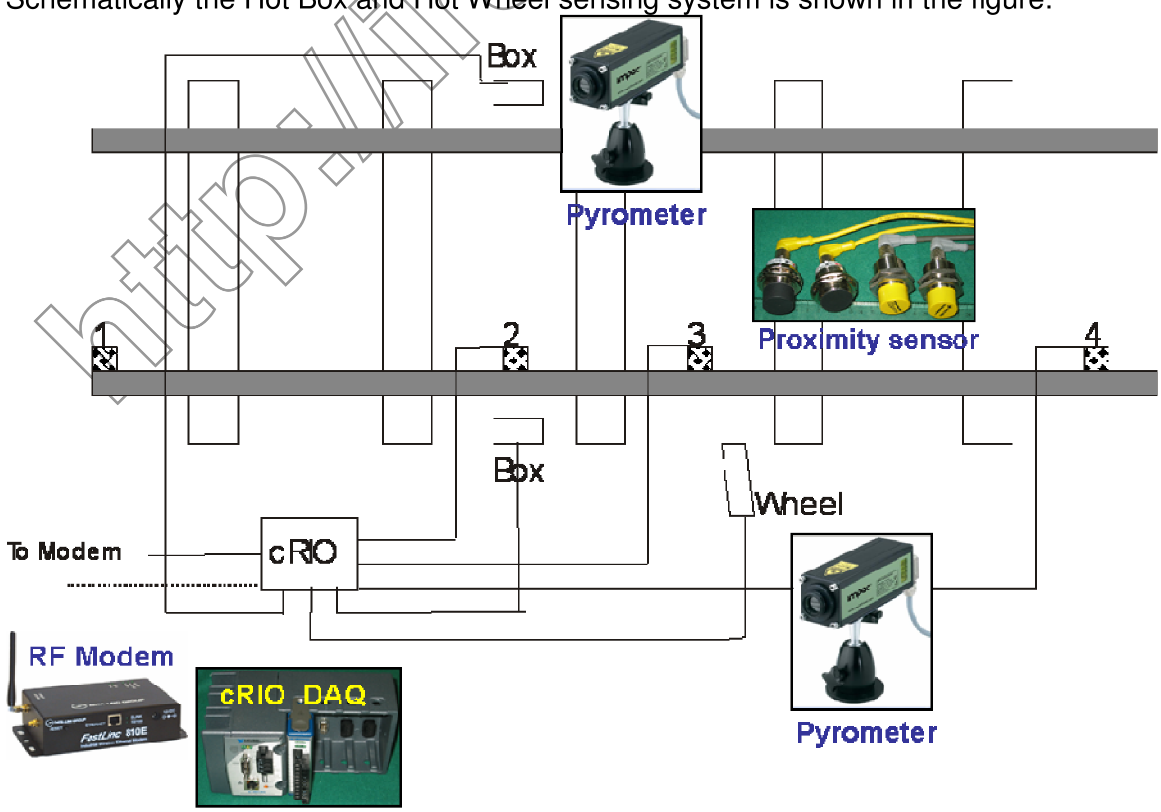
When a measurement is made, the environment surrounding the sensor will also be radiating into it. The thermal signal will also emanate from the sensor itself. This is seldom an issue when the temperature being measured is much higher than that of the sensor and its environment. However, in the case of a hot-box this is not the case since

the temperature to be measured (say 70°C, i.e., 343K) is less than 30 degrees above the ambient in summer, i.e., a temperature difference of less than 10%.
One way to overcome this dilemma is to cool the sensor. This was a tall order outside the confines of a laboratory till recently. However now sensors with built-in thermoelectric (TE) coolers (working on the Peltier Effect) have become available. Modern day TE coolers are capable of reducing the temperature by ~30-40°C. By cascading these coolers lower temperatures can be achieved. A three-stage cooler can attain a temperature of around -60°C. If the sensor is mounted on this then it will offer a good signal to noise ratio.

Present day sensors are essentially of two varieties. They may me either micro-bolometric or photo- (conductive and voltaic). A micro-bolometric detector relies on the radiation falling on a tiny resistor which is heated, and the change in resistance measured. Micro-bolometric systems with response times in the 10ms region are available. However, the use of these sensors is being rapidly overtaken by the use of semiconductor sensors. For these sensors narrow band-gap semiconductors like Lead Selenide (PbSe) and Mercury-Cadmium Telluride (MCT or HgCdTe) are frequently used. In the case of MCT the bandgap (and hence the working wavelength) can be tuned by changing the Mercury-Cadmium ratio. These sensors offer a response time which is at least three orders of magnitude faster than the best micro-bolometric sensors. Photoconductive sensors are more popular than photovoltaic sensors.

MCT sensors with integral three-stage TE cooling are being used for developing the hot box, hot wheel detector. These sensors provide adequate sensitivity and have a fast response (~2µs). The signal levels are however lower than in the case of micro-bolometric sensors demanding a higher (and better) amplification. These sensors are available in both single element units, as well as one and two dimensional arrays. The array sensors find use in infrared imaging systems. Due to the defence applications of these in missile guidance, and night vision, their availability can be problematic. However, single element sensors are not likely to face these problems.

Implementation:
Schematically the Hot Box and Hot Wheel sensing system is shown in the figure:



There are four inductive proximity sensors (# 1 to 4) and three thermal sensors shown as Box and Wheel in the figure. All the sensors are connected to the cRIO chassis, which in turn feeds the modem for the wireless transmission of data to Control Office.

Proximity sensors 1 and 4 are used to detect the approach of the train and start the system. They can also be used for opening and closing the shutters of the housing of pyrometers. Sensors 2 and 3 are used to define the 'window' for temperature measurements for the box and wheel, respectively, define the train direction, estimate the speed of the train and also count the axles in the train.

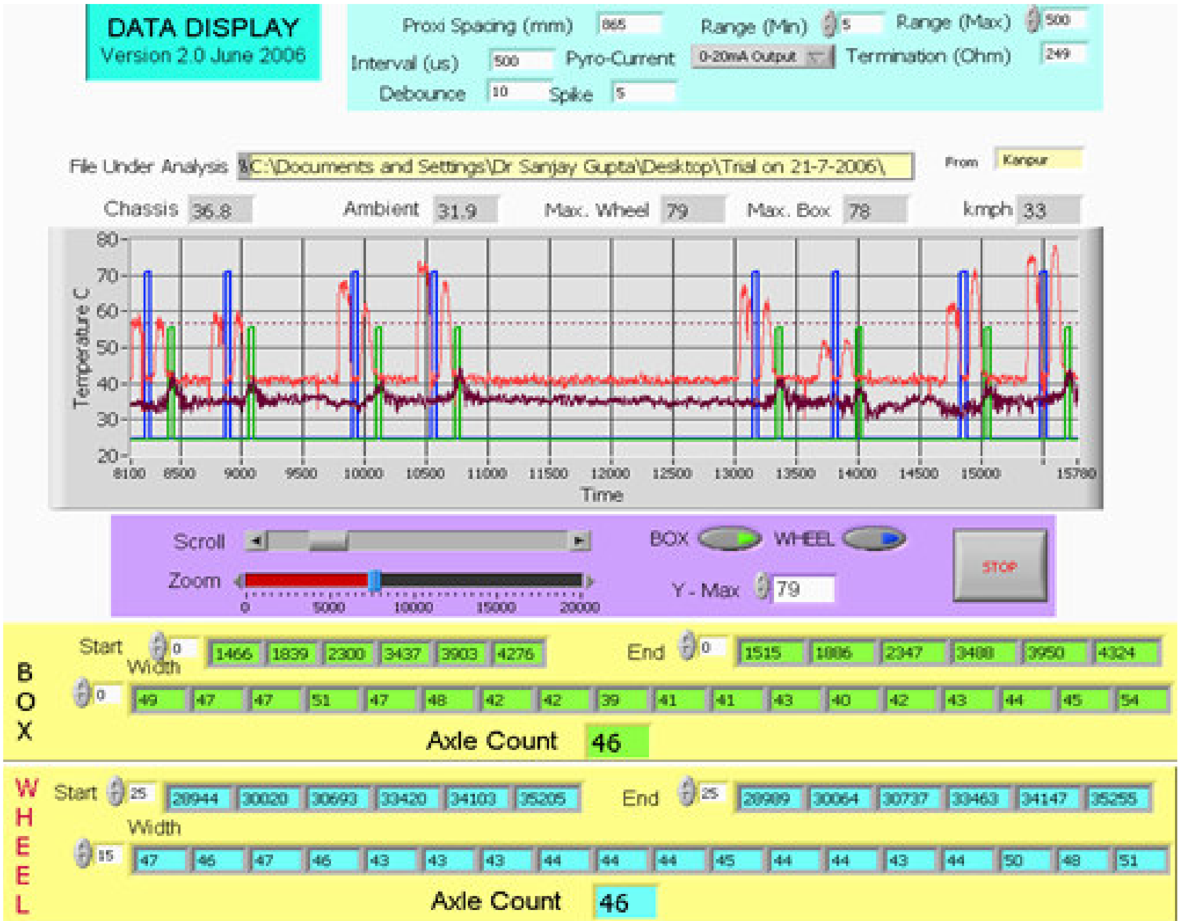
Even though the boxes and wheel have to be monitored at both sides of the track, the number of sensors can actually be reduced to three. This is done by using a single sensor to measure the wheels at both the near and remote side. The box sensors look vertically above the plane of the figure at the bearing boxes. The wheel sensor is however mounted at an angle so as to be able to sense the temperatures of the far wheels during the gaps in the near wheels.

After processing in the cRIO chassis the signals are then sent through the modem to the mother computer in Control Office or TXR's Office. cRIO comes equipped with both Ethernet and RS232C (and now also USB) ports; any of them can be used for the interface.

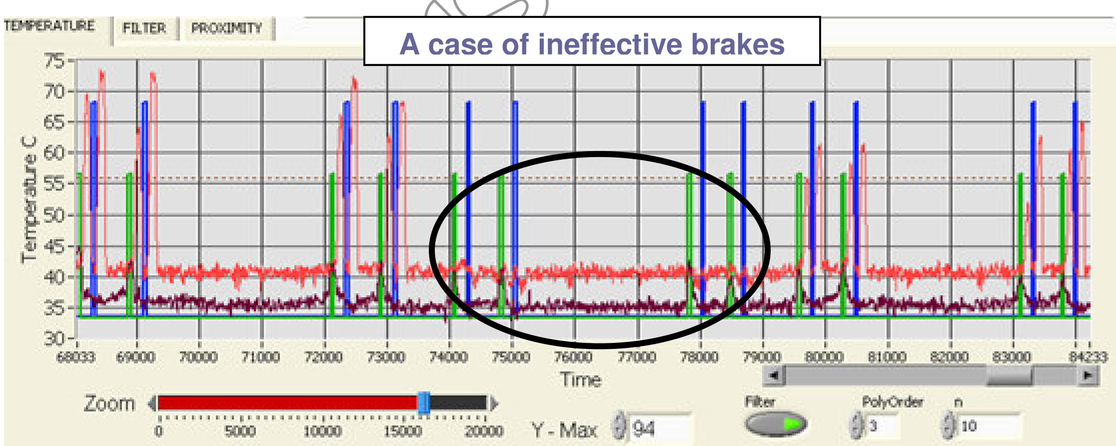
Initially, off the shelf pyrometers have been used to develop the software and collect data to fix the threshold limits. These pyrometers can reliably measure temperatures on trains running upto 60kmph.These will be subsequently replaced by MCT sensors for detection at higher speeds.

A display of the data recorded in a running train is shown below. The signals in green & blue are from the proximity sensors and help in locating the box and the wheel temperatures respectively. The signal in brown is the temperature recorded by the box pyrometer while that in red is the temperature recorded by wheel pyrometer. It may be seen that the temperature in red on either side of wheel proximity sensor (blue) corresponds to the temperature of the two wheels of an axle. The proximity sensor signals also help in counting the number of axles in the train. In absence of Automatic Vehicle Identification system #, the vehicles with abnormal temperatures have to be identified through axle count.

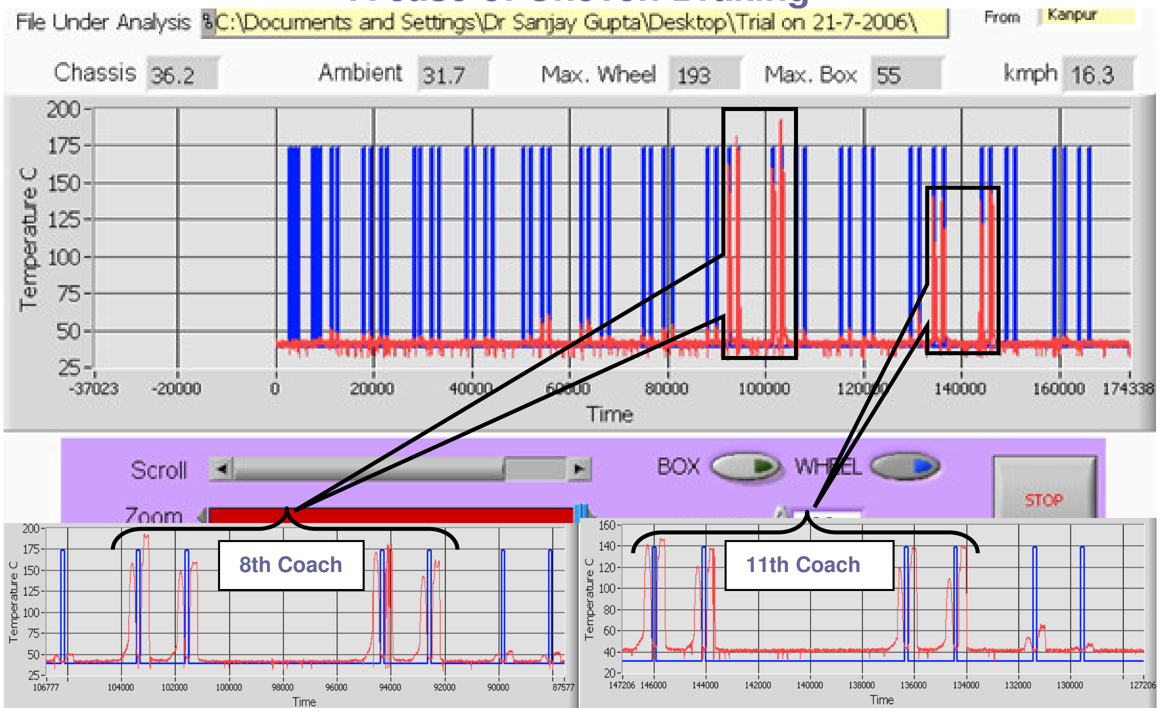
 # Automatic Vehicle Identification using RFID has been field tested upto 150 kmph in another project with IIT, Kanpur, viz, "Trackside Bogie Monitoring System".



Cases of ineffective brakes and uneven braking in coaches detected by the system by comparing the wheel temperatures are shown below:-



A case of Uneven Braking



The temperature of 8th & 11th coach wheels exceeded 140° C while the wheels of remaining coaches remained below 70°C.

Conclusion:

An intelligent infrared sensing system for detecting hot box due to bearing failure, hot wheels due to brake binding and cold wheels due to ineffective brakes can be a useful tool in the hands of maintenance staff and can contribute to the safety and reliability in train operations.