

# Detection of Transverse Defects in Rails Using Noncontact Laser Ultrasound †

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**Abstract:** Rail inspection is required and aims at ensuring safety and preserving the availability of railway infrastructure. According to the statistics published by world railroad administrations, the transverse fissure appearing in railhead is the principal cause of rail accidents. These particular defects are initiated inside the railhead. Detection of these cracks has always been challenging to perform as defect signature remains mostly small until the defect size reaches a significant value. The present work deals with the theoretical analysis of an integrated contact-less system for rail diagnosis, which is based on ultrasounds. The generation of these waves is performed through non-ablative laser sources. Rotational laser vibrometry was used to achieve the reception of the echoes. Detection of flaws in the rail was monitored by considering special ultrasound wave signal based indicators. Finite element modeling of the rail system was performed, and transverse defect detection of the rail was analyzed.

**Keywords:** Rail; transverse fissure; contact-less system; ultrasound; laser; rotational laser vibrometry

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## 1. Introduction

In the early times, rail inspections were done visually. During the past century, various detection methods were introduced to get the state of rail health even if the defect has not yet reached the rail surface. These include eddy-currents, infrared thermography, and ultrasonics [1–3]. The ultrasonic technique was recognized to be suitable for operating the detection of transverse like flaws. The early detection of these defects constitutes then a challenge to improve the security of railways and to prevent catastrophic failures.

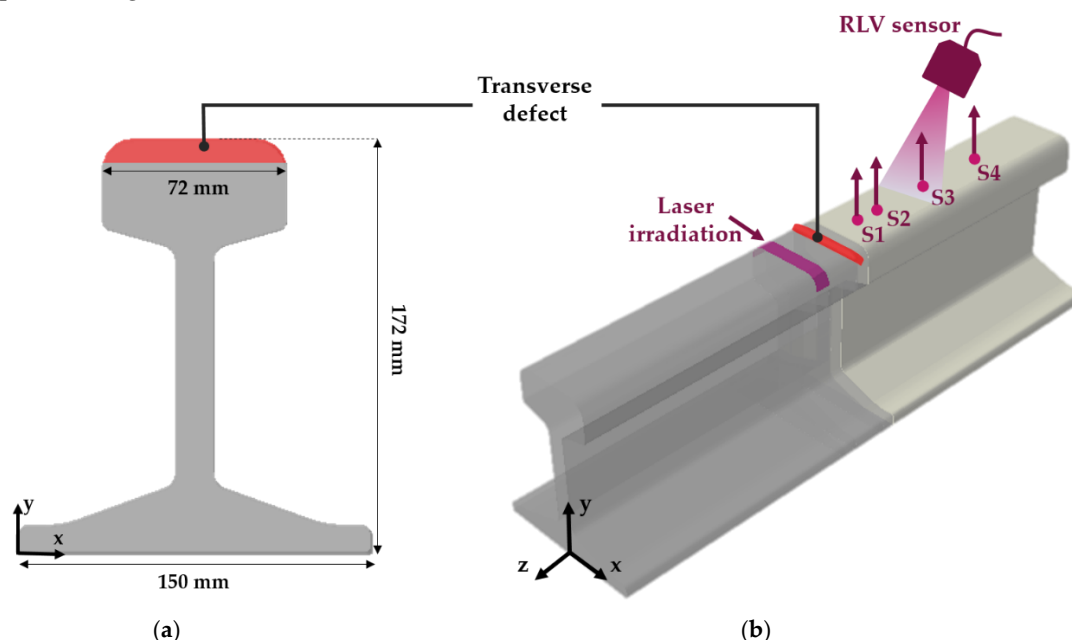
Ultrasonic based inspection techniques of railways utilize the phenomenon of elastic wave propagation. The excitation method can be performed according to a contactless pulse-echo configuration, based on laser-generated ultrasound. The reflection of elastic waves may occur at a defect present in the rail system, and the generated echo can then be sensed. A contact-less ultrasound sensor consisting of a rotational laser vibrometer that performs reception of reflected echoes from defects is considered. The simulation of ultrasonic wave propagation was done on ABAQUS software. The wave is assumed to be generated from a laser-irradiated spot, located on the railhead. The reception of rail response is performed by a laser vibrometer sensor.

The purpose of this work is to identify the optimal position of the sensor to capture the information and to improve the detectability of flaws as earlier as possible.

## 2. Materials and Methods

### 2.1. Material Properties

The rail structure considered in this work is made from a linear homogeneous and isotropic elastic steel material. The total length of the rail is  $L = 600$  mm. The position of a localized transverse defect was halfway between the transmitter and the receiver as shown in Figure 1. The material properties are given in Table 1.



**Figure 1.** (a) The geometry of the rail 60E1; (b) The localization of RLV reception sensors, transverse defect, and the spot excitation zone for rail inspection.

**Table 1.** Material properties of the rail structure.

Material Properties	Value
Young's Modulus (GPa)	210
Density (kg/m <sup>3</sup> )	7800
Poisson's ratio	0.3
Conductivity (W/(m.K))	50.2
Specific Heat (J/kg.K)	490

### 2.2. Defect Geometry

Transverse defects can range from surface defects to internal cracks [4]. The geometry of the defect is rectangular and has 5 mm in depth. Table 2 shows the parameters of such a defect.

**Table 2.** Parameters of transverse defect located in the rail.

Defect Volume in (mm <sup>3</sup> )	Defect Length in x	Defect Width in z	Defect Depth in y
700	72 mm	2 mm	5 mm

The detection of this type of flaws has been monitored through a special ultrasound device that generates ultrasonic signals using short, focused laser irradiation on the top head of the rail, and senses the back-reflected echo.

### 2.3. Rail Inspection Method

The method of excitation uses a laser ultrasound transducer that includes a single laser spot irradiation to excite the railhead. In this case, the spot size is chosen to be 15 mm in width and 72 mm in length.

For the reception of wave signals, a sensor termed Rotational laser vibrometry (RLV) is used to measure the deformation caused by propagating ultrasonic waves. RLV is a contact-less device that allows measuring very accurately the angular velocity and the angular displacement generated by elastic deformation on the rail structure. In this work, the RLV is calibrated to measure the normal velocity with the y-direction at several positions of the rail, as can be shown in Figure 1.

### 3. Results and Discussion

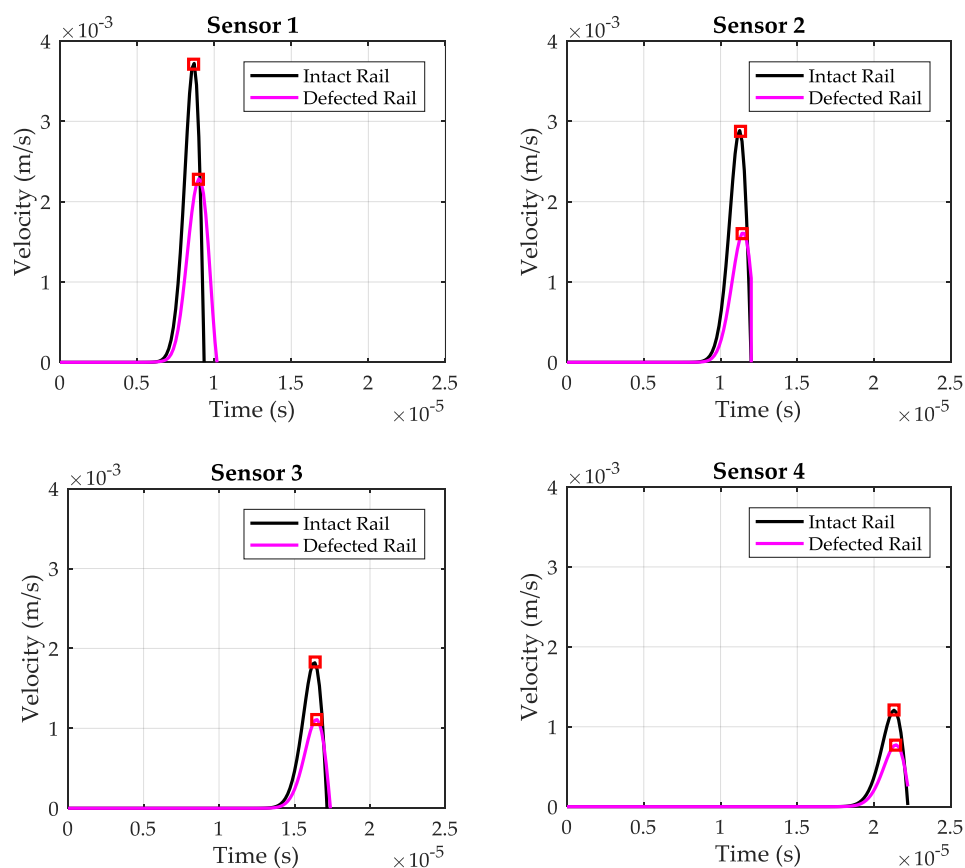
A finite element model of the proposed diagnostic device was developed using ABAQUS software. The model was simulated for a rail with defect and intact rail.

The use of sensors here is to determine the normal velocity at each chosen position. The goal is to identify the best position of the sensor to capture the information and to minimize the number of sensors as much as possible.

To avoid the perturbation resulting from the reflected waves, an algorithm in MATLAB software was developed to select the peaks of only the first received signals, as can be shown in Figure 2. The location of the chosen sensors are detailed in Table 3.

**Table 3.** The positions of the sensors from the transverse defect and the excitation spot zone.

	Sensor 1	Sensor 2	Sensor 3	Sensor 4
<b>Distance from the transverse defect</b>	15 mm	30 mm	60 mm	90 mm
<b>Distance from the excitation zone</b>	50 mm	65 mm	95 mm	125 mm



**Figure 2.** The results of the four sensors, for the case of rail with transverse defect and intact rail.

The velocity of the propagated wave is decreasing in the presence of the defect, as can be shown in Figure 2. Sensor 1 can capture the signal faster than the other sensors, because of the distance that separates the position of the sensors, from the defect and the spot excitation area, see Table 3. The signal amplitude increase when the sensor position is closer to the defect. These results indicate that the location of the sensors has a significant effect on the amplitude. For that, the number of sensor can be reduced as the sensor 3 and 4 capture the signal late than the first two sensors; and the amplitude for both intact and defected rail turn to decrease.

#### 4. Conclusion

The most important fact revealed at this level of the study is the influence of the position of the sensors on the signal amplitude. Each sensor captures information depending on the distance that separates the sensor from the defect and the spot area, and once the distance changes, the influence of the amplitude changes also. The obtained results have enabled to determine the best arrangement of sensors positions to operate the detection of transverse rail defect.

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