

CRACKED RAIL SPIKE DETECTOR PRE-PROPOSAL

ECE 480 Design Team 4

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Executive Summary:

Norfolk Southern Railroad Co. requires a device to efficiently detect railroad spikes that are at risk of failure due to undetected cracks. Team 4 proposes to develop and test a prototype detection system based on ultrasound technology. The system will be compact and portable for field deployment, have sufficient energy storage to run for four hours without recharging or swapping batteries, and will be capable of detecting cracks of 1/4" in railroad spikes. The prototype will be lab tested using a test bed constructed from actual railroad spikes in various states of failure, provided by Norfolk Southern Railroad Co..

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Introduction:

Problem Overview:

From the initial ECE 480 project description:

“When the spikes holding rails to ties crack, the crack is sometimes undetected until it the top of the spike breaks off, typically from a fatigue crack 1-2 inches from the head of the spike. It may be undetected until the rail rolls over. Then the spike must be driven through the tie, and replacement is difficult. Norfolk Southern would like a device (perhaps ultrasonic) designed and prototyped that could be placed (like a cane) on a spike top and would detect whether or not that spike is cracked or is broken through. The device must be convenient to carry, must not draw excessive battery power, and must provide an indication that is easy to read even in bright sunlight. Optionally, the device might be able to mark a cracked spike automatically.”

Customer Requirements:

Norfolk Southern Railroad Co. has sent specifications for a device that will be used to identify rail spikes that are broken or cracked. A prototype of this device is to be implemented and tested by Design Day, December 11, 2009. The testing method must be non-destructive and capable of detecting cracks *in situ*. The customer suggests ultrasound as a sensing method, but this is not a requirement. The device the customer envisions would be placed on the spike head by an operator using a cane-like implement and identify whether or not the spike is cracked or broken through. Ergonomics and light weight are identified as key design factors, as the device is expected to be used by an operator is expected to be walking along the railroad. For construction materials stainless steel tubing or aluminum tubing are suggested, but not required, by the customer.

Norfolk Southern Railroad Co. has over 22,000 miles of track with ties approximately 19.5 inches apart. Each tie has two plates with two to five spikes per plate; with so much to test, a high capacity battery back with on-site recharge capability is clearly desirable. Power economy is a major design criterion. The speed with which the device makes its decisions is a concern: the faster it can give a pass/fail answer, the faster the operator can move on to the next spike. Ideally the device would return a result within a few seconds. The device must be used outdoors, requiring appropriate weatherproofing. Decisions must be easily read by the operator in bright sunlight as well as a range of illumination conditions in the field. One optional “bonus” suggested by the customer is a display for the depth of the defect in the spike. This information could assist the determination of whether the spike needs to be removed, but it will add to complexity, cost, and power consumption.

A target accuracy of detecting a crack of $\frac{1}{4}$ inch is specified. Too much less sensitive and the device would miss dangerous flaws, too much more sensitive and there is a danger of false positives with normal corrosion and pitting. Another optional request made for this device was to automatically mark the spike if tested and found defective; the preferred colors are orange and yellow, as these are used to mark other defective railroad parts.¹

Background:

Nondestructive Testing Options:

Among the most common forms of nondestructive testing used in industrial applications are eddy current testing, acoustic testing, and ultrasonic testing.² We investigated the pros and cons of these various options.

Eddy Current Testing:

Eddy current testing works by sending an electromagnetic wave into the substance to be tested and observing the perturbations in the wave caused by flaws in that substance. Unfortunately for our purposes, the strength of eddy currents decreases exponentially with depth. The concern is, will the current be strong enough to penetrate deep enough to detect flaws in railroad spikes? Generally, the limit of useful detection is considered in the field to be one “standard depth of penetration”, which is defined as the depth at which the wave has 1/e or 37% of the strength it had at the surface of the material. The formula for this standard depth in millimeters is as follows:

$$SDoP = \frac{1}{\sqrt{\pi * f * \sigma * \mu}}$$

(Formula from Joseph M. Buckley)

where f is the frequency of the test wave, μ is the magnetic permeability of the substance being tested, and σ is the electrical conductivity of the substance being tested in % IACS.³ For steel, the relevant properties are:

$$\sigma = 0.1$$

$$\mu = 1000 * \text{the magnetic permeability of free space, or } 1.26 * 10^{-3}.^4$$

To detect every flaw, the wave needs to penetrate 5 inches into the spikes, so the depth of penetration must be at least 127mm. Solving for frequency in the above equation, we find that the frequency needs to be less than 0.157 Hz, or a wave with a period of several seconds. This is not feasible. The limiting factor is the high magnetic permeability of steel, as compared with aluminum.

Acoustic Testing:

Acoustic testing is a simple method: one strikes the object to be tested, and then listens to the tone it produces. The idea is that “good” parts will produce different sounds from “bad” parts. The problem is, human judgement is can be highly fallible, and training operators to recognize the distinction can be expensive. Therefore, computers are used to analyze the waveforms of the sounds produced, running them through a Fourier transform to isolate frequencies that are expected for the part being tested to produce, and contrasting them with abnormal frequencies that could indicate a flaw. This analysis requires a dedicated microchip to perform, which can drive up the cost, complexity, and power consumption of our device. Additionally, the customer has expressed concern as to whether the varied conditions of the spikes in the field will allow for a consistent auditory

signature to be developed. If the metal and the ground damp the resonations in different ways at different times, it could be difficult to develop a meaningful set of reference frequencies.⁵

Ultrasonic Testing:

The basic theory behind ultrasonic testing is similar to acoustic testing: it works by striking an object and analyzing the sound produced. However, in ultrasonic testing, the object is struck with waves of high frequency sound, and the sound being analyzed is an echo bouncing off the interior of the object. The typical ranges of ultrasonic waves used in non-destructive industrial testing are between 2-10 MHz. (This is much higher than the ultrasound used in medical applications.) The typical way ultrasonic testing is conducted is by taking a piezo transducer, using some a grease layer to couple it to the part being tested so that sound does not escape, and sending a pulse of sound into the part. Then, when the pulse reaches a barrier (such as a flaw, or the edge of the part), some portion of the pulse will be reflected, and the transducer will pick up this reflection and send it to a microprocessor to be processed. Flaws are distinguished from edges by the return time of the reflection. The speed of sound in the medium the part is composed of should be known, so the expected return time of the reflections from the edges can be calculated. Reflections at any other time, then, indicate a flaw in the part.^{6,7} Experiments have been done by Schubert et. al. showing penetration of 169 mm (more than the 127 mm we need to achieve) in rails, which are similar in composition to the railroad spikes we need to test. The goal of the project, then, is to adapt the methods which are already in use into a convenient package for field testing the spikes on the railroad.⁸

Design Specification:

The main objective of the spike detector is to test for the presence of internal cracks that could cause spike failures. The use of ultrasound waves will be a very efficient way of testing the spikes as ultrasound has great properties to penetrate metals. The reflected signals received from within the spike will give the data needed to determine whether the spike is defective. Another very important goal is the ability to analyze the data received from the reflection within the spike. The average failure point for the spike is roughly 3 inches from the top of the spike. Using this data we can determine a specific range where cracks are most likely to exist and filter out all other signals received from the spike.

The cracked rail spike detector must be compact and easy to handle. A railroad technician must be able to walk the tracks testing the individual spikes efficiently and comfortably. This is a major concern for our team and Norfolk Southern. The application of a couplant on the spike is required for the ultrasound transceiver to work properly. "Couplant is generally necessary because the acoustic impedance mismatch between air and solids is large. Therefore, nearly all of the energy is reflected and very little is transmitted into the test material"⁹

Another concern that must be factored in is total power necessary to run the device. The detector must be able to run for at least four hours on a battery charge to allow the user to work efficiently in the field. A rechargeable battery pack is identified as the most practical source of power because this device could be used multiple times a week and charging it would save on overall operation costs. This battery pack may have to be attached to the

waist or back of the operator to permit mobility.

Simplicity in the way the results are displayed is also a concern. A simple yes or no answer is required in this case because the user is either going to leave the spike or have it removed. Producing a full display of the received ultrasound waves is unnecessary in our case. That level of precision is unnecessary, and it would add to the cost of the device. However, a display that provides a reading of the depth at which the crack is present within the spike could be useful. This data could provide a better understanding of the stress on the rail spikes and could lead to better quality spikes in the near future.

One very crucial requirement is sensitivity of the ultrasound receiver. “If the sensitivity is too defined the sensor can pick up small corrosions and pits within the spike”¹⁰ The sensor must be able to detect cracks that are at least a quarter inch in length. This gives us a good range to work with when creating and testing prototype. Marking defective spikes is another concern we will address. Once a faulty railroad spike is found by a railroad technician it must be clearly marked for removal in a weatherproof manner. This adds another mechanical attachment to the overall design but it is a component which the customer has requested. The last parameter that needs to be closely monitored is the overall cost of the device. There are devices on the market that could accomplish the tasks Norfolk Southern has asked us to address. The key factor is that the cost is substantially higher than a product we could create. Cost will be the factor that puts us ahead of the competition.

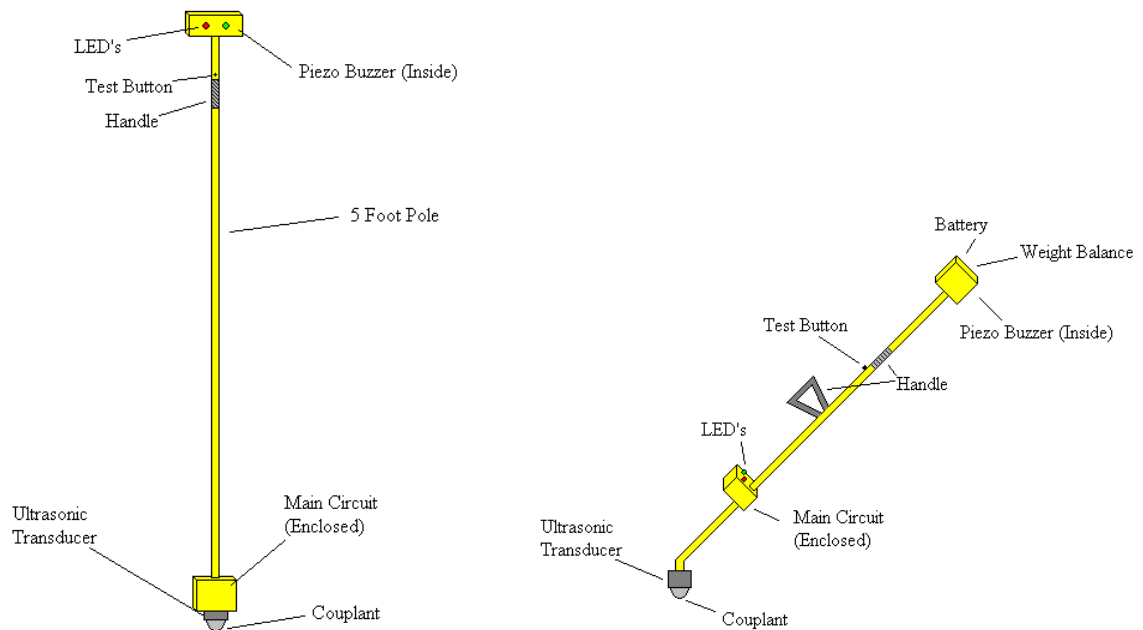
Conceptual Design:

For displaying the results of the testing, three concepts were proposed. The first was a simple LED-buzzer combination that would provide a binary result as to whether or not the spike was flawed. The second was a 7-segment display that would indicate the depth of the flaw. The third was a monitor that would display the waveform of the reflected ultrasound pulse.

For the data processing circuitry, there was a choice between an analog solution and a digital one. The analog solution would comprise a bandpass filter for the received signal, and a threshold detector for determining if the filter had detected a flaw of sufficient size. The digital solution would process the data via an IC, comparing the received signal to a reference.

Two overall form factors were considered. The first was a device in the shape of a vertical pole, which the operator would position over the spike being tested. The LEDs would be placed at the top of the pole, near eye level for the operator. The second was inspired by metal detector designs, and consisted of a diagonal pole which would be strapped to the operator’s shoulder. See Figure 1.

FIGURE 1: Form Factors



Two different construction materials were discussed, PVC piping and stainless steel.

Whatever design was adopted, it would need a couplant layer between the transducer and the spike being tested. The only feasible way of including this couplant layer was to put a rubber cap containing the couplant on the end of the device. Also, any design would require an orange industrial marker at the bottom to identify flawed spikes.

See below for a solution selection matrix (Figure 2).

FIGURE 2: Solution Selection Matrix

Engineering Criteria	Importance	Possible Solutions								
		Boolean LED and Buzzer	Monitor	Depth Gauge (7 Segment)	Analog	Digital	Metal Detector Style	Pole Style	PVC	Stainless
Visibility	5	●	▲	▲			○	●		
Weight	4	●	○	●	○	○	○	○	●	▲
Ergonomics	4	●	○	○			●	○		
Power	3	●	○	●	○	●				
Speed of Response	2				●	○				
Weather Proof	3	○	▲	○					○	○
Accuracy	5	▲	●	○	○	●				
Durability	2	○	▲	○	○	▲	▲	○	▲	○
Total Points		120	98	82	52	92	65	71	43	19

▲ = 1	○ = 3	● = 9
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During discussions with the customer, visibility was repeatedly emphasized as a key factor. Thus, it has been ranked as maximally important, along with accuracy of results. Speed and durability were somewhat downplayed, so they have been ranked with an importance of 2.

Note that the metal detector form factor has been rated as lower durability than the pole form factor. This is because the pole is a simple straight piece, whereas the metal detector has angled joints.

Project Plan:

Design Solution:

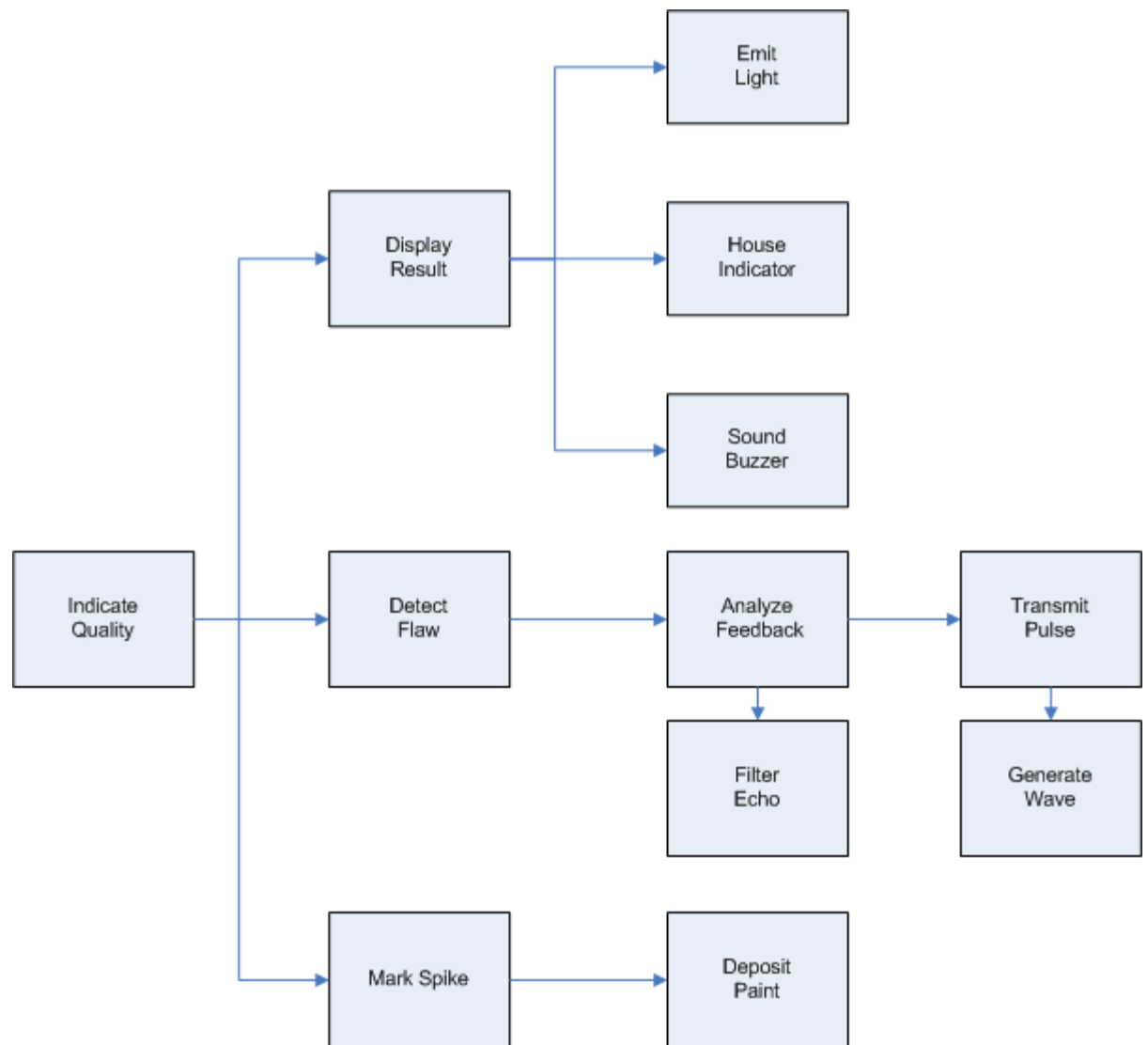
From the data in the solution selection matrix, a design was created. It would communicate with the operator by means of an LED and buzzer, it would use digital processing to classify spikes, it would have a pole-shaped form factor, and it would be constructed of PVC piping.

Test Plan:

The test plan is to test our prototype on actual railroad spikes, both flawed and good, which will be provided by Norfolk Southern. A test bed will be created with these spikes resting

in a medium which simulates field conditions. The device will be considered successful if it can pick out the flawed spikes from the good ones with 95% accuracy. The device will also be taken outside on a sunny day to verify that the display is easy to read. It will be considered successful on this score if an operator can immediately tell what information it is conveying even in direct sunlight.

FIGURE 3: FAST Diagram



Risk Analysis:

Norfolk Southern is aware of the breaking spike problem and has taken measures to study the cause of the breakage. They have identified the forces involved and have identified remedies that counteract these forces. Once these remedies are implemented as planned, any defective spikes that are undetected by our device will be replaced with little to no consequence. This reduces the risk to the railroad from a failure in the device. One major risk this project runs is failure to receive proper testing materials. Without flawed and intact spikes to run tests on, it will be difficult to properly calibrate and test the device, and there is a risk that a system will be created which is of no use in actual practical situations. A moderate risk comes from the large proportion of the budget which is taken up by a single transducer: if this transducer breaks or fails to work as expected, there will be insufficient funds for a replacement.

Project Management Plan:

Assignment of Technical Tasks:

Geoff Brigham

- Assemble casing
- Attach features
- Design and assemble user interface portions.

Chad Church

- Design and assemble power supply.
- Testing of power supply.

Ronald Fox

- Design an assembly of rubber gel pad for detector.
- Integrate the detector and IC's.
- Testing of functionality

Matt Hamm

- Gather materials for assembly.
- Design and assembly the hardware for the IC's.
- Integration of all components.

John Vogel

- Program the IC to receive input, calculate output and return result.
- Develop algorithm to detect spike flaws.

Schedule:

A Gantt Chart is available in the appendix (Figure 4).

Budget:

Item	Quantity	Cost
LEDs	2	\$2
Resistors	20	\$2
Capacitors	20	\$2
Rubber pad	1	\$10
Ultrasound Gel	1	\$20
Electromagnetic Transducer	1	\$250
Programmable Memory device (IC)	3	\$10
Clock (IC)	1	\$1.50
Circuit board	2	\$4
Spool of wire	4	\$10
Triggers (switches)	3	\$3
Industrial Marker	1	\$10
PVC piping	6ft	\$5
	TOTAL	\$329.5
	Total Budget	\$500

References:

- 1: Hayden Newell, Norfolk Southern Railroad Co., Personal Communication
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- 3: An Introduction to Eddy Current Testing and Technology, by Joseph M. Buckley, available online at joe.buckley.net.
- 4: Introduction to Electromagnetic Compatibility, textbook by Dr. Clayton R. Paul, p. 301
- 5: Resonant Acoustic Method Delivers Defect-Free Parts, by Richard Bono and Scott Sorensen, in Advanced Materials & Processes, July 2008, p. 25
- 6: Automatic Fault Detection Using Ultrasonic Techniques by J. Arce, available online at <http://ieeexplore.ieee.org>
- 7: Nondestructive Material Testing with Ultrasonics by Michael Berke, available online at www.ndt.net
- 8: Ultrasonic Testing of Rails with Vertical Cracks, by Frank Schubert, Bernd Koehler, Olga Sacharova, available online at www.ndt.net
- 9: Introduction to Ultrasonic Testing, available online at www.ndt-ed.org
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