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RAILWAY SOLUTIONS

Technology Review of Autonomous Rail Switch Heating System- "Blue Point"

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NIBE Element Railway Solutions
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“Today we consider our business concept to be intelligent heating and control.”
- Mr. Christer Fredriksson, Director of Business Area, NIBE Element

TABLE OF CONTENTS

SUMMARY

The main purpose of the article is to introduce a revolutionary rail switch heating system – Blue Point and Dual Elements. Thanks to "*Intelligent heating and control*", the system features four critical attributes that are top priorities for a rail switch heating system:

- Ensuring uninterrupted operations, reliable under any weather conditions.
- Responding to weather conditions autonomously, cutting energy consumption whenever possible, avoiding potential property damage due to uncontrolled overheating or fire.
- Provide real-time operational status of switch heaters and sensors year-round.
- Minimum needs for replacement or maintenance to realize cost savings in maintenances.

Such a system has been introduced by K. M. Clyne and J. H. Andersson in a US Patent "Rail Switch Heater" - US 10,858,787 B2" published in December 2020[1]. The system has the following specific features:

- Extreme Heat: Supply Extreme Heat instantaneously and reliably under occasional and rare conditions of snowstorms or blizzards, protect the rail switch from freezing, and avoid interruption of railroad operations with confidence. The extra heating capacity ensures the complete melting of snow and ice under extreme winter conditions.
- Energy Efficient: Intelligently and autonomously control the heating power if weather condition improves, keep the rail switch from freezing, and cut down the consumption of energy whenever possible at the same time. Since the heating power is reduced, the service life of the heaters is extended to avoid frequent replacement of heaters.
- Redundant: Provide redundancy and operational flexibility by using dual elements. Change out the failed element can be done easily and avoid interruption of operations. The dual elements virtually cut down the workload by half and double the service life of the heaters.
- The autonomous nature of Blue Point makes the switch heating system extremely reliable – the internal SCADA system is continuously running while allowing the external SCADA system to view or override base on solid communications – if those communications are compromised Blue Point continues to operate – there is no dependence on outside communication.

In this article, a brief review of the rail heating elements is provided in the beginning. Critical product improvements aimed to overcome shortfalls associated with short service life and high operational costs are described next. The redundant dual elements with a flat profile are introduced as the most advanced development that can achieve the desired service longevity and provide operational reliability and flexibility. The sheath material Monel 400 alloy used for the flat element exhibits the greatest heat transfer efficiency from the element to rail. The flat elements are delivered in a straight configuration and make intimately tight contact against the rail surface, eliminating the gaps frequently seen for the tubular element which are coiled upon delivery. Then, the concept and features of the latest development on "Blue Point" control will be illustrated, which is an intelligent detection and control system that regulates the power level to the highly robust dual heating elements installed on the rail switch.

The main advancement in the patented technology for the rail switch heating system is the use of dual or redundant heating elements driven by an intelligent power control – the Blue Point control. The Blue Point works under the scheme of Pulse Width Modulation controlling a high-frequency operations relay such as a Solid-State Relay(SSR) which in turn drives the dual elements heater. The Blue Point selects a suitable duty cycle to regulate the heating power to the elements automatically. The power level is determined to be just enough for the measured or forecasted environment data, such as ambient and

track temperatures, humidity, and wind speed as provided by the sensors and a dedicated weather station. The system can also be operated manually if needed to accommodate extreme heating demands.

Compared to existing technology, there are many advantages by using Blue Point and Dual Elements:

- Solid and highly reliable performance in all weather conditions, ranging from near freezing or frost to mild freezing sleet or snow, to snowstorms with gusty winds or blizzards lasting for hours to days.
- Full awareness of the functional status of the rail switches and sensors.
- Greatly cut the needs and frequency to replace a failed heating element, especially in the middle of a blizzard. This is due to the huge increase in system service life as a result of dual heating elements and smart power control using Pulse Width Modulation (PWM).
- Significant and tangible cost savings in maintenance, operation, and replacement (MOR) by eliminating unnecessary energy consumption and avoidance of unplanned replacements.

INTRODUCTION

The Issue

Figure 1 shows a photo of a train rail switch where the "Switch Rails" and "Running Rails" are indicated[2]. The Switch Rails can be shifted back and forth using the sliding "Switch Rod" to make contact with only one of the two Running Rails at any given time. When the Switch Rail is closed with the Running Rail on the right side, the train will travel from the bottom to the upper left direction. Similarly, if the "Switch Rail" is closed with the "Running Rail" on the left side, the train will be directed to the upper right tracks.

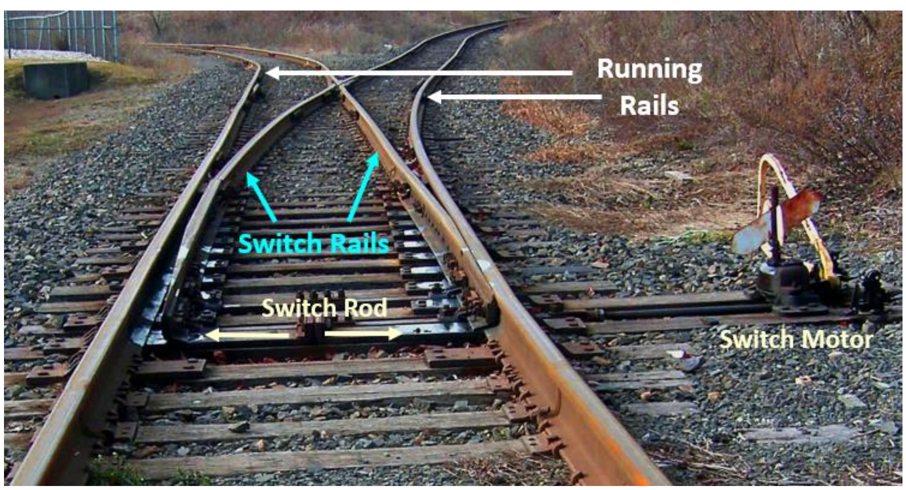


Figure 1 Rail Switch

Under freezing weather conditions, the rail track switch can be jammed if it is frozen. The Switch Rail can no longer be separated from the Running Rail and close in with the other Running Rail. In this case, the train may only travel in one direction which is dictated by the frozen switch. Thus, a buildup of snow and ice, if ignored, will interrupt railway operations, the vehicles are forced to take diverging routes which causes severe delays to service. Most seriously, freezing of rail switch may lead to derailments causing property damage and even loss of lives. For this reason, rail switch heating has been developed.

The Original Rail Track Heater – Tubular Heating Element

The original electric rail switch heating uses a so-called Tubular Heating Element to de-ice the tracks[3]. Figure 2 shows the construction of such a Tubular Heating Element. The heating element is made of a straight or linear resistance wire of alloys, typically Copper-Nickel (Cu-Ni) or Cupronickel, Nickel Iron (Ni-Fe), Nickel Chrome (Ni-Cr) or Nichrome, and Iron Chrome Aluminum (Fe-Cr-Al). Different resistance wires are selected primarily for their maximum operating temperature, ranging from 572^{o}F (300^{o}C) to 1400^{o}F (2552^{o}C).

The alloy wire is embedded and compacted with Magnesium Oxide (MgO) powder, which serves as the electrical insulation. The element is then completed with a tubular metal sheath typically carbon steel, stainless steel, nickel alloys such as Inconel and Incoloy, etc.

When voltage is applied between the two opposite ends of the resistance wire, heat is generated and transferred through the MgO and outer metal sheath to the ice or snow on the rail. A constant voltage is applied by a switch next to a circuit breaker or fuses to control the power on/off. Under the fixed voltage, the heat is generated by the tubular element at a constant wattage regardless of the ambient temperature, until the power is cut off manually by an operator. If the power is not turned off when there is no snow or ice on the rail, electricity is wasted, and the heater may burn out causing potential property damages in some serious circumstances.

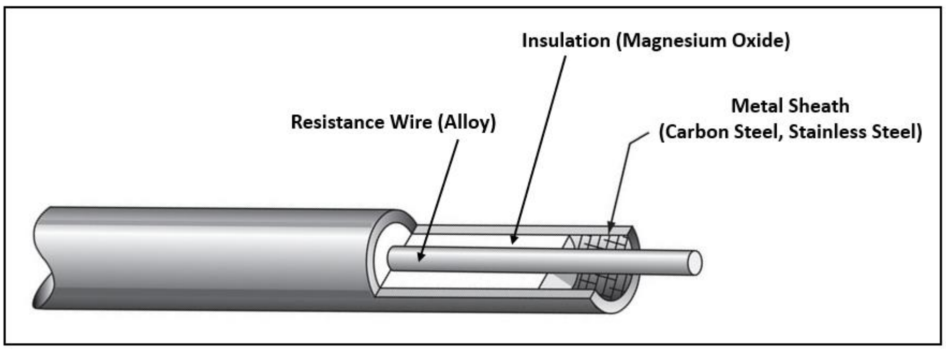


Figure 2 Illustration of a Tubular Heating Element

It did not take long to realize that the service life of Tubular Heating Element is unacceptably short, lasting from a few hours to a few weeks, most probably within one winter season. It appears that several factors contributed to the rapid failure.

- The first factor is the fact that MgO powder is highly hygroscopic, it is prone to moisture ingress through imperfect end seals, causing MgO to lose its dielectric strength or electric insulation between the resistance wire (the conductor) and the metal sheath.
- Secondly, the resistance wire undergoes expansion and contraction in response to the temperature changes associated. The expansion coefficient of the alloy wire could be disproportionally greater than that of the MgO and outer metal sheath, causing loss of concentricity of the resistance wire inside the tubing and eventually creating shorts between the wire and metal sheath or tubing.
- Thirdly, after installation the heating element will be deflected due to expansion, the entire heating element may bulge out and separate away from the track. When expansion deflection occurs, the heat transfer efficiency is greatly reduced, the body temperature of the element itself will increase drastically and the element will burn out quickly.
- The fourth factor is the incompatibility of surfaces between the round tubular element and the flat rail track. The Tubular Heating Element, when originally designed, worked well for heating liquids and air where the element is immersed or in good contact with the medium. It suffers, however,

from an obvious disadvantage for rail heating applications as there is an incompatibility between the curved surface of the element and the flat surface of the rail track. It is estimated that the contact area for a tubular heating element with a rail track is only about 15%. Heat is dissipated wastefully through convection and radiation into the air, only a small portion of heat is transferred *via* conduction through the small contacting area between Tubular Heating Element and rail. To melt snow and de-ice, the element must be overpowered to compensate for the low efficiency of the heat transfer. The overburden or stress of the heating element for an extended duration is an important factor for the element to fail rapidly.

- The fifth factor is coiling memory. Tubular heaters are normally delivered in a coil. When the heater is uncoiled it still retains some coiling memory. This coiled memory creates gaps to the rail, so the heat sink is not as good as a heater that has not been coiled – such as a straight flat switch point heater.

Frequent replacement of failed Tubular Heating Elements during snowstorms, especially for those installed with direct burial that requires excavation, is not only difficult but also dangerous and in many instances impossible. Attempts to mitigate the problems of rapid failures by replacement of tubular heating elements have been made by users[3], but with mixed results. Installation methods ranged from the insertion of the Tubular Heating Element in protective pipes to direct burial. Frequent failures, however, continually occurred and so often that all heaters in stock during a heating season were used up.

HEATER IMPROVEMENTS

Some important improvements on the track heating have been made:

- Change the heating element from cylindrical or rod-like to a flat profile or belt/tape to enlarge the contact area between heater and rail.
- Use of Alloy such as Monel 400 as the outer sheath material, which is impervious to water, salt, and resistant to most chemicals.
- Change the shape of the embedded resistance wire from linear to helical.
- Use of insulation material to cover up the heating element on the surface that is facing the air.

Flat Heating Element

Figure 3 illustrates the situations when heating elements are installed around the web-foot of the rail. It is calculated that the contact area between a round tubular element and a flat surface is about 15%. If the element is flattened to a belt or tape, then, the contact area increases to about 40%.

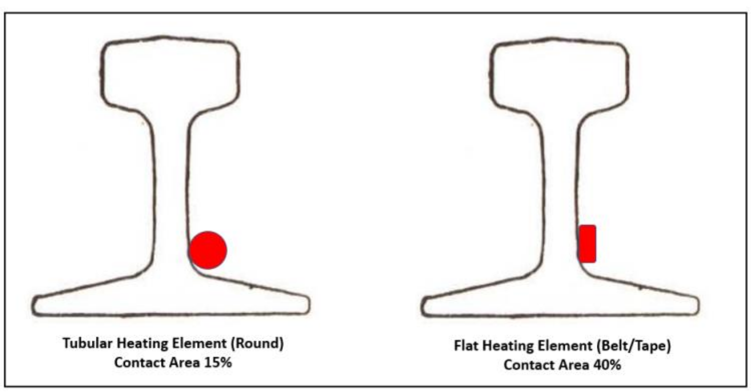


Figure 3 Illustration of Contact Areas of Heating Elements with the Rail Web

As the contact area increases, conduction of heat becomes more effective which reduces the required power output of the heater. The reduced power output requirement can extend the service life because the stress on the wire is reduced and, at the same time, realize cost savings on energy consumption.

Service life and cost-saving for flat heater have been studied by White & Fitzgerald[3]. When both heating elements, round and flat, are installed on switching rail tracks under comparable operating conditions, the flat heater worked continually after two years without sign of failure, compared to less than three months for the round tubular heating elements. Costs saving due to reduced heater output for the flat element ranges from 55% to 63%, which can quickly offset the higher purchasing cost for a flat heater. Flat Heating Elements are made commonly from rod-like Tubular Elements by manufacturing processes that involve annealing, swaging, bending, or profile pressing. This process is a matured know-how that ensures the resistance wire is symmetrically embedded in MgO powder and well separated from the metal sheath throughout the entire length of the repressed element.

Examples of Flat Track Heaters are shown in Figures 4 and 5, which are made by San Electro Heat A/S in Denmark, a subsidiary of NIBE Elements.

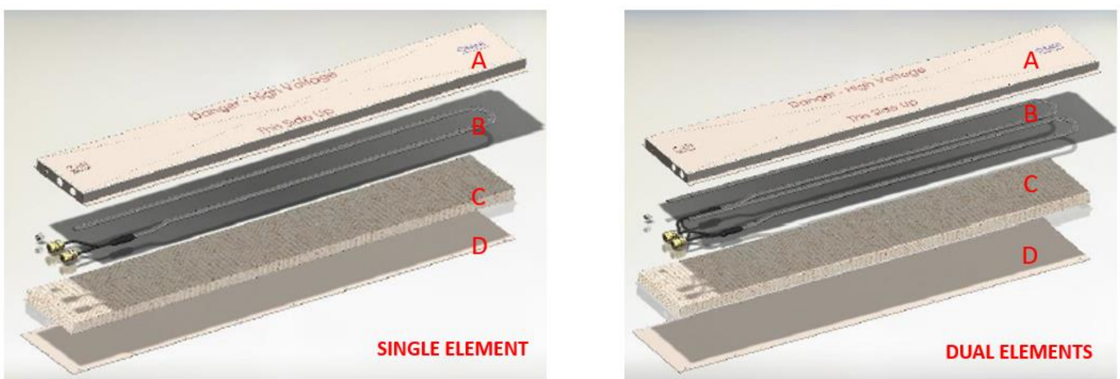
Figure 4 Flat Heating Elements
Left: with Lead Wires and Power Junction; Right: Installed on the Rail (Single Element)

Figure 5 Flat Heating Element Installed on the Rail
Left: Single Element; Right: Dual Elements

PAN Heaters

An upgrade of flat heating element for heating of switch machine rod is the development of the PAN heater by San Electro Heat. It is made by encasing either the round or flat heating elements using metal plates, such as stainless steel or highly corrosion-resistant Monel 400 Nickle-Copper alloy, and then sealed into place. The design allows for a slide-in-place installation under the switch machine rods with the added protection of the pan enclosure versus a bulky, messy crib heater. Figure 6 shows examples of such PAN heaters with one and two heating element configurations.

It can be recognized that by using the metal casing (Face A in Fig. 6), the heat generated by the heating element can be spread evenly over a much-increased area of direct contact with the switch machine rod, thus, increases the heat transfer efficiency. With the same amount of heat transferred over a larger area (lower surface watt density), the temperature of the heating element "B" can be reduced which is important to prolong the service life of the PAN heater. Component "C" in Fig. 5 is a thermal insulation that effectively stops the heat exchange between elements "B" and Casing sheath "D". Face "D" is away from the switching rod or exposed to air. Therefore, heat wasted into the air is now redirected through Casing sheath A and applied onto the rail. Avoidance of waste heat by insulation further reduces the wattage required of elements. Lower wattage decreases the burden of the heating element "B" and cuts the cost of electricity. The combined effects by increasing contact area and insulating the element on one side made two improvements: prolong the heater's service life and reduce the cost of energy consumption.



A. Top Sheath facing track, SS or Monel 400; *B. Flat Heating Element*
C. Thermal Insulation; *D. Bottom Sheath away from the track, SS or Monel 400*

Figure 6 Examples of PAN Heaters

As shown in Figure 6, PAN Heaters, offered by San Electro Heat and Omni Control Technologies, have two options: single element and dual elements. The dual elements version provides for a redundant heat solution in the event of element failure. It is beneficial to operate both elements simultaneously at 50% burden or capacity, further prolonging the service life of both elements which is a cost-saving on the labor of frequent replacement and maintenance. The PAN heaters shown above have been installed and are functioning for several years. The products are covered under a standard warranty of 3 and 10 years for stainless steel and Monel 400 sheaths, respectively.

Sheath Materials

Common sheath materials for tubular heating elements are carbon steel, type 304 and 316 stainless steel, copper, and nickel alloys INCOLOY®, INCONEL®, and MONEL®. For the application of rail switch heating, the most critical properties are corrosion or weather resistance, thermal conductivity, mechanical strength over a wide range of temperatures.

Carbon steel is an excellent choice for its high thermal conductivity (about 45 W/m.K) which makes heat transfer very effective and is the least expensive raw material. When facing a rail environment, however, it tends to corrode, rust, and disintegrate quickly within months and renders the product unusable.

Stainless steels 304 and 316 are better choices than common carbon steel in terms of corrosion resistance but is not impervious to water, acid rain, and liquid of road salt, *etc*. Corrosion can take place within a year or so under the northern weather conditions. The thermal conductivity for 304 and 316 decreased somewhat to 14.0 and 13.0 W/m.K, respectively, compared to 45 W/m.K for carbon steel.

INCONEL® and INCOLOY® alloys, containing a large amount of nickel and small amounts of chromium and iron, are known to exhibit substantially improved corrosion resistance in harsh environments. They are, therefore, a favorable choice of sheath materials by many manufacturers of tubular heating elements even the cost of materials is significantly higher than stainless steel. Because of increased nickel content, the thermal conductivity is decreased further to somewhere between 11.2 W/m.K.

Monel 400 (UNS 04400) is an alloy of Nickel-Copper (70:30 roughly) and minor contents of Iron and Manganese (2 to 2.5% of each). It exhibits resistance to a wide range of corrosive conditions. It is most frequently applied in a range of environments going from mildly oxidizing through neutral and moderately reducing conditions. It is widely used in marine applications. The thermal conductivity is 22.8 W/m.K, which is lower than carbon steel, but noticeably higher than that of stainless steels, INCONEL®, and INCOLOY® alloys. Thus, the choice of Monel 400 is a balance between corrosion resistance and thermal conductivity. Like other nickel alloys, Monel 400 maintains its mechanical strength under sub-zero or cryogenic temperatures. Table 1 lists the main characteristics of the metals for the sheath of tubular heating element[4].

Table 1 List of Materials and Characteristics Critical to Sheath of Heating Element

Material	**Corrosion Resistance**	**Thermal Conductivity (W/m.K)**	**Cost ($/lbs.)**
Carbon Steels	Poor	36 to 54	0.6
Stainless Steel 304/316	Modest	14.0	1.5
Incoloy 825	Good	11.1	12.3
Inconel 601	Good	11.2	11.0
Monel 400	Good	22.8	12.0

Monel 400 Flat Element vs Stainless Steel Tubular Element

There are significant differences in performance between the two types of heating elements which are both used for rail heating nowadays. Comparisons are made between the two types of elements by considering the two main perspectives: Thermal Transfer Efficiency and Element Attachment Gaps.

- Thermal Transfer Efficiency

Consider three ways of heat transfer: (1) Conduction – most important as it is by direct contact between element and rail; (2) Convection – inefficient as heat is dissipated into the air; (3) Radiation – also inefficient as the heater is not hot enough to generate radiation. The three ways of heat transfer are depicted in the figure below.

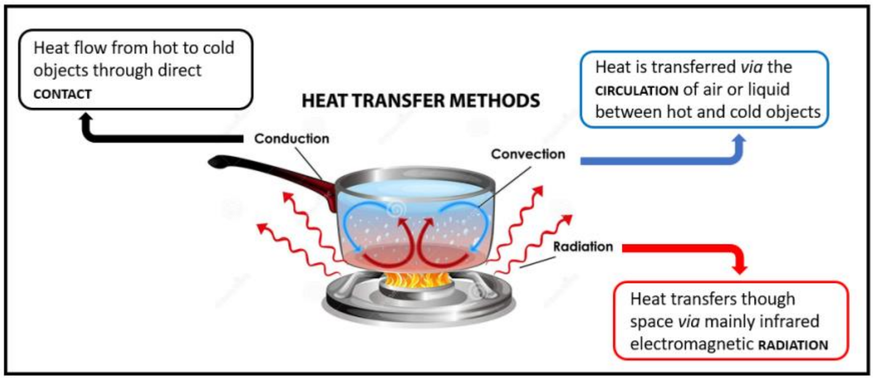


Figure 7 Demonstrations of Heat Transfer

Therefore, for rail heating using heating elements, only conduction heating needs to be considered. The efficiency of heat conduction is given by the equation:

$$W = k\, A\, (\Delta T) / d$$

where,
W is the rate of heat transfer or efficiency to be compared,
K = thermal conductivity, Monel 400 (Flat Element): 22.8 W/mK, stainless steel (Tubular): 14.0 W/mK,
A = contact areas for one inch of length. For flat Element, the width is 0.52" and the contact area is 0.52" x 1" = 0.52 in^2; for tubular element, the contact area between a round tubular element and a flat surface is 15% of the tubular surface, the diameter is typically 0.49", thus, the contact area per one-inch length is 15% x 3.14 x 0.49" = 0.23 in^2,
ΔT is the temperature differential between the heater and the rail,
d = the sheath thickness of the heating element,
Consider *ΔT* and *d* are equal between Flat and Tubular

Thus, the ratio of heat transfer efficiency between the two types of elements, W_F/W_T, are:

$$W_F/W_T = (22.8*0.52) / (14.0 * 0.23) = 3.68$$

Because of the advantages in thermal conductivity and surface shape, the flat Monel 400 sheathed element has a clear advantage in heat transfer to the rail. A 250 W/Ft flat heaters can attain up to 3.67 times more efficiency than a tubular heater and easily surpassing the tubular element with a nominal power output of 400W/Ft to 500W/ft.

- Element Attachment Gaps

The gaps are an undesirable feature, they are formed between element and rail during installation. This applies to both round tubular and flat heating elements. As shown in the illustration below in Figure 8, this is because the element has been coiled up for easy shipment from the factory to the job site. The coiled element is up to 24 feet long and the coil diameter is approximately 3 feet, or 2.5 rings or circles. During installation, an effort is made to extend the coil into a straight line. Since the "coil" has its memory or tendency to coil up and resists straightening, thus, tight contact against rail over the entire length of the element is practically impossible. A gap against the rail is formed in the middle of the two fixing clips which is typically 1 to 2 feet apart. To attach a 24-Ft element, there will be 12 o 24 fixing segments, therefore, there will be on the average of 18 such gaps between element and rail. It is estimated that the average length of a gap is about 15% of the clip distance, or 0.15*1.5 Ft = 0.225 Ft, then, the total distance of the gaps over a 24 Ft element is 18 x 0.225 = 4.05 Ft or 16.9%. Therefore, the additional heat loss due to the gaps is 16.9%.

On the other hand, if the element is shipped in a straight configuration, then, the installation can be made with intimate contact between the element and the rail, and the gaps are eliminated. Shipping elements in a straight length of 24-Ft adds difficulty and complexity in logistics, but the benefits are easy installation and increased thermal transfer from the element to rail, and it has been standard practice by NIBE Element Railway Solutions.

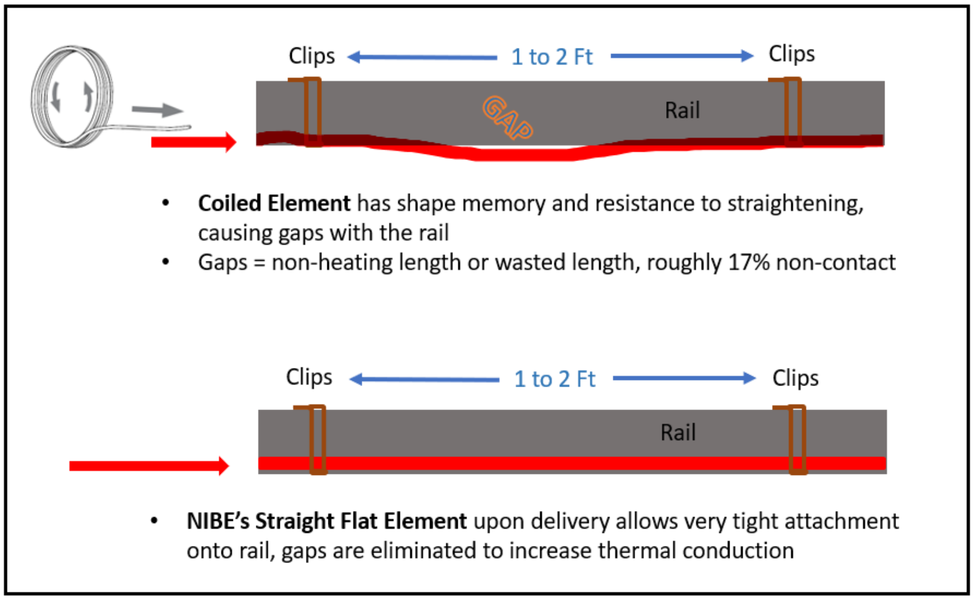


Figure 8 Demonstration of Element Attachment Gap and Its Elimination

Figure 9 demonstrates the gaps on some of the typical installations due to the coiling of elements upon delivery, and installation of the NIBE flat element without coiling which eliminates the gaps between element and rail.

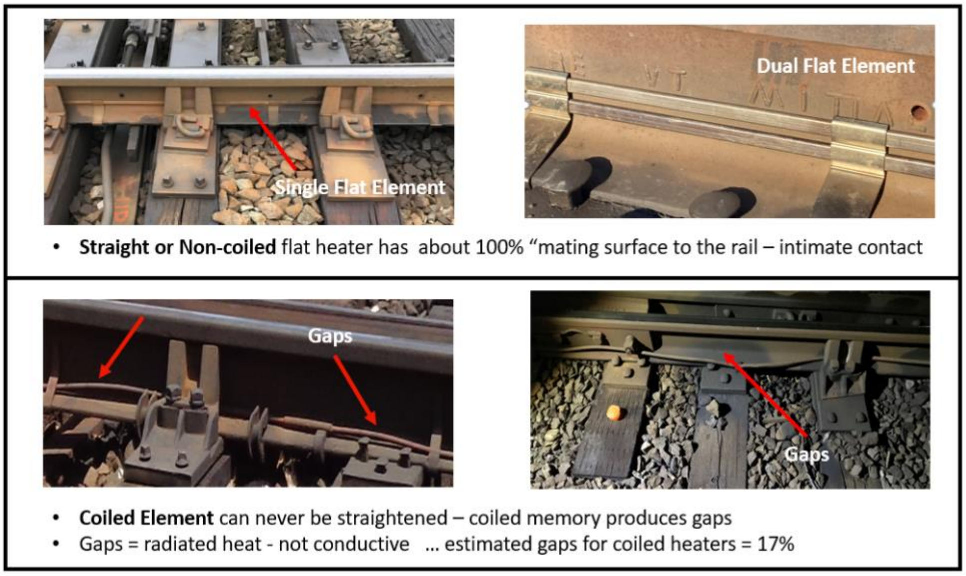


Figure 9 Comparison of Installations between Straight Element (top) and Coiled Element (bottom)

Helix Resistance Wire

To overcome the issue of mismatch of expansion coefficients among different materials, *i.e.,* resistance wire, surrounding MgO, and metal sheath (tubing), which leads to rapid product failure caused by shorts between resistance wire and sheath, the heating elements are arranged to assume the shape of a helix. The helix coil is still embedded by MgO powder and contained within the outer metal tubing.
Figure 10 depicts such an arrangement. The helical resistance wire may add manufacturing complexity, but MgO filling stations commercially available to most manufacturers of heating elements are highly capable. The added cost of the extra wire length due to coiling is justifiable because of the benefit of extended service life. Users are advised to specify the design of the helix resistance wire inside the tubing if possible.

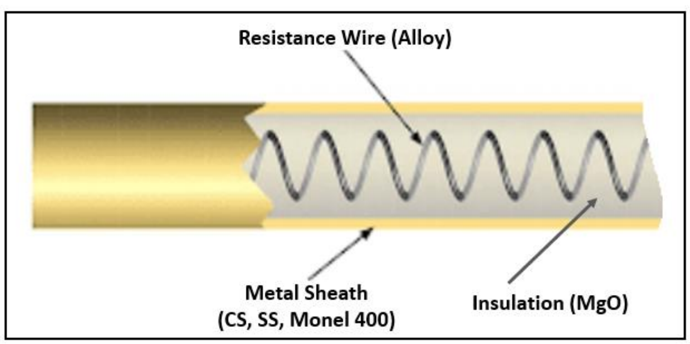


Figure 10 Demonstration of a Tubular Heating Element with Helical Resistance Wire.

The Use of Insulation Materials

As already shown in Figure 6 – construction of the PAN Heaters, a layer of thermal insulation can be applied to cover the side of the element that is away from the track. The insulation is protected by a metal sheath as in the PAN heaters. The insulation cover or panel on the heating element can effectively block the heat transfer to the ambient, therefore, further reduce the burden of the heating element to prolong the heater service life and save the cost of electric energy.

There is a range of inorganic, flame-proof insulation materials suitable for high-temperature applications, such as fiberglass, CMS wool, super wool, ceramic fiber, polycrystalline fiber (made primarily of aluminum and silicon)[5]. Commercially available elastomeric foams used as low-temperature thermal insulation, such as foamed polyurethane (FPU), however, are not suitable as the high surface temperature of the heating element will degrade, decompose, or ignite the insulation made of organic polymeric materials.

Dual Heating Elements with PWM

The epic of heater improvement for rail switch heating is the introduction of Dual Elements or redundant heating elements as depicted in Fig. 5 (right).

The main features are:

- A flat surface facilitates high efficiency of heat transfer compared to the round tubular element.
- Helix internal heating element allows for expansion and contraction of the element with minimal impact to the element versus a straight wire element (most common), therefore, extends the life of the element.
- Monel 400 alloy as the sheath material is more thermally conductive by many times compared to stainless steel and is impervious to salt and most chemicals.
- Reduced dimensions without the sacrifice of performance allow install in constraining space at the switch point, special considerations are made on the design and fabrication of the heating element to fit on the rail web or under the switching machine rod. For example, the dual element heaters are unique in that they can both fit in the gap of a Arema brace using specially designed stainless steel clips. This would not be possible with other switch heating elements.

The benefits and advantages of using Dual Elements are:

- Capable of delivering extreme heat with two elements working together in blizzard weather, which is the top priority for switch point to be freezing-free and operatable.
- Provide operational flexibility and redundancy - when one of the two heating elements fails, the system may be configured with just one element that still functions with its maximum heat output by ramping up the duty cycle PWM %. Allow enough time for railroad maintenance personnel to replace a failed component without the downtime of railroad operations.
- Prolong the service life by at least 2 times – when both elements are working at the same time, as the workload or thermal stress for both elements is reduced by 50%.

THE CONTROL SYSTEM

The next significant improvement for Rail Switch Heating System is the use of a Control Panel for regulating the power to the heating elements or heaters. The control panel along with the temperature sensors, temperature controller, and heaters makes up a complete thermal control system. The goal is to heat the rails only when it is needed and with a power level that is just enough with the weather conditions. This is the business concept: intelligent heating and control.

When heating power is adjusted by the control panel according to the weather conditions, the benefits are further enhanced in terms of (a) increased service life of heaters, and (2) incremental cost savings up to 70%. Other advantages include operational consistency and reliability by autonomous process, *i.e.,* "Man Out of The Loop".

The control system may be designed to control multiple heating elements that are installed at different locations on the rail. Each location can be controlled independently of other locations by using the data from the location-specific sensors.

The control system provides the operator full awareness of the status of the switch heating system and the conditions on the track by monitoring and detecting the heater's working conditions. Diagnostics are continuously performed on the heaters, sensors, and communications. Should an error occur the system will notify the supervisor through the call center. This notification will be handled based on the severity of the error – for instance, a failed heater during a snowstorm will deserve an email and call to the supervisor regardless of time but a failed heater in July will require an email only. More details on an advanced control system for rail switch heating system is described in the next section.

THE BLUE POINT RAIL SWITCH HEATING SYSTEM

The combination of Blue Point control and Dual Elements heater represents the most advanced rail switch heating system[6] to date. Prominent features of the system include:

- Extreme Heat mode with Dual Elements delivers extreme heat during winter storms or blizzards, prevents the switch from freezing up, and ensures uninterrupted railway operations.
- Intelligent heating modes with just enough power levels come into play for less severe conditions. The heating power can be automatically regulated according to the weather conditions, provide significant cost savings on energy consumptions, and extend the service life of elements.
- The Dual Elements provide redundancy and operational flexibility. Replacement of one failed element can be done easily without disturbing the use of the other element.
- Blue Point control can provide awareness of system status, predict and notify the operator, via the call center, of any abnormalities for intervention to avoid interruptions of railroad operation.

The Blue Point Control

Figure 11 shows the principles of the switch heating system consists of Blue Point control and Dual Elements. The system functions autonomously in reacting to various weather conditions[6].

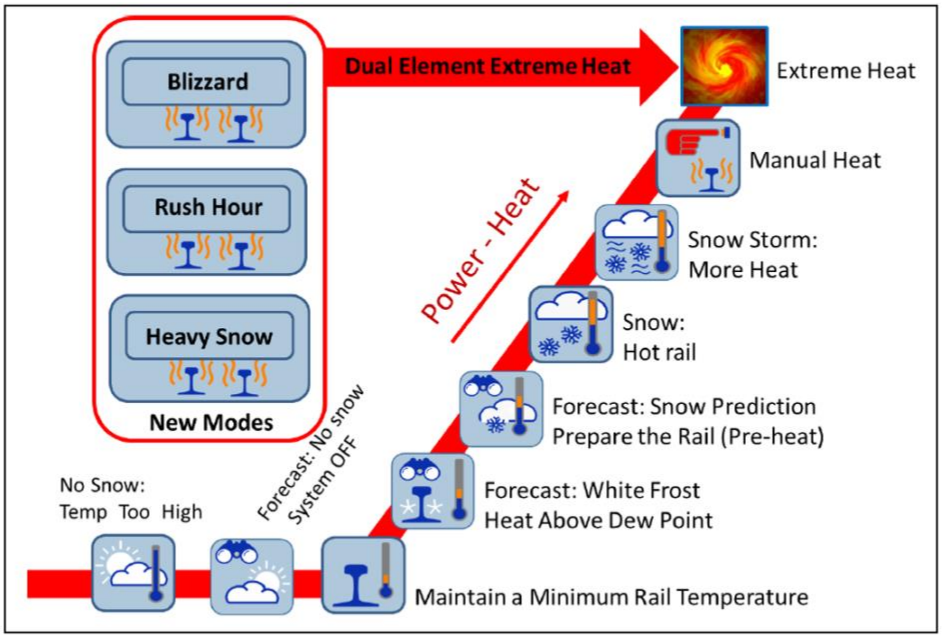


Figure 11 The Power of Heating Is Regulated Based on Weather Conditions

The autonomous nature of the Blue Point is an added safety factor to ensure the system is running in a robust and reliable state – it does not require any outside coordination or communication to operate – it can run by itself. Blue Point makes itself available to the Blue Point cloud for viewing status, loading the database, diagnostics, and can override. Even if communication for weather prediction is lost, the system keeps working with its internal SCADA system, the system will depend 100% on the weather station and continue to control and monitor. The bottom line is there is no need to have an operational relationship between the Blue Point Cloud and the physical Blue Point Controller.

Pulse Width Modulation (PWM) by Blue Point Control System

Traditionally, when the applied voltage is set by the facility, the output of a heating element is constant at its maximum rating by design to handle the worst scenario of ice prevention. If heating at full power is left alone to continue when the ambient is already warm, the element will overheat and burn out. Manual interference by switching on or off the heating element is not only labor-intensive or tedious but also misses out on opportunities to save energy.

To accommodate varying weather conditions as shown in Fig. 8, the power output to the heating elements is varied by the Blue Point control accordingly. This is accomplished by the control system equipped with programmable logic controller (PLC) and a high-frequency operations relay such as a Solid-State Relay (SSR). Variable power output is made possible by turning one or more heating elements On and Off in a predetermined duty cycle and with a specified duration of the period within a full cycle. Blue Point controller typically uses 40 seconds as the period of one cycle, or the sum of ON time and OFF time.

Single heating elements can achieve 250 W/Ft, for example, when energized continuously which is the same as 100% duty cycle. The same element could also achieve a 125 W/Ft under the same facility supply voltage by energizing with a duty cycle of 50%, or 20 seconds ON followed by 20 seconds OFF during a complete one cycle, and 100 W/Ft output by energizing with a duty cycle of 40%, or 16 seconds ON followed by 24 seconds OFF during a cycle.

Similarly, for dual elements, a pair of 250 W/Ft heating elements can achieve a total output of 500 W/Ft when both are energized continuously or at 100% duty cycle, which may be needed with a good safety factor for extreme weather conditions such as a blizzard. A target heating power 300 W/Ft under the same facility supply voltage can be achieved by energizing both elements with a duty cycle of 60%, or 24 seconds ON followed by 16 seconds OFF, which is suitable for white frost condition and the rails need to be heated to above the dew point.

Table 2 shows exemplary settings of duty cycle in pulse width modulation (PWM - %) to vary the heat output for single and dual elements, corresponding to different "Exemplary Weather Conditions".

Table 2 Duty Cycles (PWM %) and Corresponding Power Outputs Under Different Weather Conditions

Output Settings (W/Ft)	Single Element PWM - %	Dual Element PWM - %	Exemplary Weather Conditions
0	0	0	No snow or no snow forcasted
50	20	10	Maintain Min. Rail Temperature
75	30	15	Maintain Min. Rail Temperature
100	40	20	Maintain Min. Rail Temperature
125	50	25	Maintain Min. Rail Temperature
150	60	30	Forecast: White Frost, Heat above Dew Point
175	70	35	Forecast: White Frost, Heat above Dew Point
200	80	40	Forecast: Snow, Pre-heat the Rail
225	90	45	Forecast: Snow, Pre-heat the Rail
250	100	50	Snow: Heat The Rail to Prevent Icing
275		55	Snow: Heat The Rail to Prevent Icing
300		60	Snow: Heat The Rail to Prevent Icing
325		65	Snowstorm: More Heat Needed
350		70	Snowstorm: More Heat Needed
375		75	Snowstorm: More Heat Needed
400		80	Snowstorm: More Heat Needed
425		85	Continued Snowstorm: Required More Intensive Heat
450		90	Continued Snowstorm: Required More Intensive Heat
475		95	Continued Snowstorm: Required More Intensive Heat
500		100	Blizzard, May Manual Set For Extreme Heat

Notes:
1. PWM - % (Pulse Width Modulation) is defined by (Time ON)/(Time ON + Time OFF).
2. Maximum output 250W/Ft per element is just an example. Other W/Ft can be designed based on actual applications.

CONCLUSIONS

Rai Switch Heaters have been continuously improved in terms of the design and materials that eventually lead to robust and energy-efficient heating elements. The original round tubular heating element started with a traditional electric heating solution, has been replaced with a flat surface and helix heating wire. The use of Monel 400 sheath material extended the service life of the heating element in corrosive environments. Thermal insulation on top of the heating element makes heat transfer unidirectional and much more efficient, which reduces the required wattage rating for the same applications. Dual heating elements, operating at the same time with reduced workload or thermal stress, further extended service life. The redundancy of dual elements provides operational flexibility and avoidance of shutdown of railroad operations.

The control system, coupled with an array of sensors and weather stations, controls the improved heating elements intelligently. The use of PWM can deliver variable power outputs just enough for any weather conditions. Precise control of rail temperature saves operating costs and prolongs the service life of the heating elements.

All the improvements made on heating elements and control systems have worked together to achieve the benefits of much longer system service life, reduced costs in energy consumption and frequent replacement, operational flexibility, and uninterrupted operations for railroad operations.

Tables 3 summarize the progress made to improve the system performance and achieve the targeted advantages. All the improvements have resulted in some increases in extending the service life of the heaters, which are listed in the table.

Table 3   Improvements and Resultant Advantages

Advantages or Goals → Improvements ↓	Provide Extreme Heat	Autonomous Control	Cost Saving on Electric Bill	Cost Saving on Replacement	Redundant Ops Flexibility	Avoid Damage (Heater Burn)
Heater with Flat Profile			+	+		
Helical Resistance Wire				+		
Sheath Material Ni Alloy				+		
Use of Insulation			++	++		
Blue Point - Control			+++	++		√
Dual Heat Elements	√		++	++	√	
Blue Point + Dual Elements	√	√	+++++	+++++	√	√

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