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Furnace Malfunction & Forensic Engineering Wiring Reconstruction

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Abstract

This paper details the fire investigation and forensic engineering failure analysis of an oil-fired furnace that had been recently installed. An underlying focus of this paper is the procedure that was used to analyze the electrical and mechanical components leading to the failure – given that evidence had been spoliated. This process demonstrates that by following a systematic investigation procedure, forensic engineers may reconstruct evidence that (in some cases) has been either destroyed or altered (whether intentionally or not) to a level that allows further insight into the malfunction.

This paper details the procedure used to document deviations from intended wiring schematics as well as the physical characteristics of electrical controls and wiring materials used in its construction. The intent of the paper is to show how this investigation procedure can be applied to other forensic investigations where electrical circuit evidence has been altered or a spoliator's identity is not readily known.

Keywords

Forensic engineering, furnace fire, fire investigation, wiring reconstruction, electrical circuit analysis, forced air furnace, high limit control

Furnace Design & Operation

The most common of all residential heating appliances in the United States is the forced air furnace. This unit transfers energy from the combustion of fuel — be it No. 2 fuel oil, natural gas, or propane — within an internal heat exchanger to the circulating air stream.

Building air is circulated along the outer portion of the heat exchanger (within the furnace jacket enclosure, **Figure 1**) and distributed through a system of ductwork supplying heated or conditioned air throughout the building.

To prevent excessive temperatures from being developed within the furnace, these appliances are outfitted with a high temperature control, commonly referred to as the high limit switch.

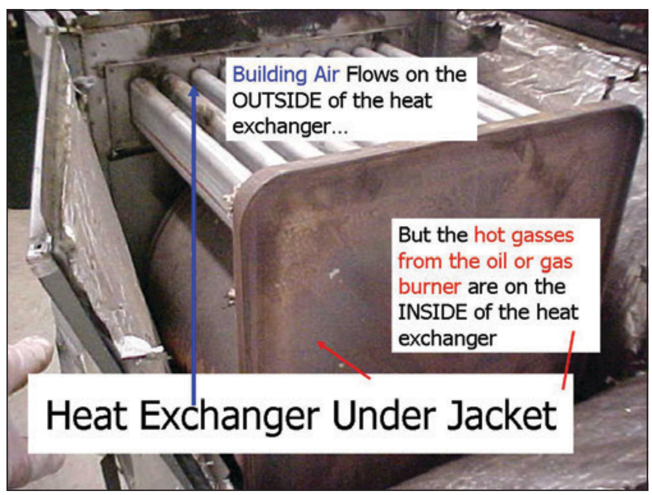

Figure 1
Forced air furnace.

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High Limit Switches

High limit (or fan limit switches) — helical coil or bi-metallic thermal sensing controls — function to shut the burner down in the event of excessive temperature. A fan limit control is shown in **Figure 2.**

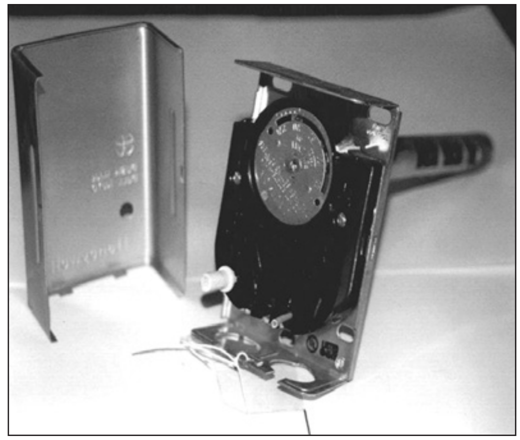


Figure 2
Fan & limit control.

Integration with Air Conditioning

In many areas of the United States, the flexibility to provide both hot air during winter and conditioned air during cooling season is accomplished by an evaporator coil installation and control arrangement allowing only one mode of operation at a time.

This allows the furnace to also function as an air-conditioning air handler fan cabinet during summer cooling months while also allowing it to provide heat during winter weather conditions.

When a forced hot air heating system is also outfitted with an air conditioning evaporator coil, a fan relay center is installed that prevents the simultaneous operation of the furnace burner and the air conditioning condensing unit. **Figure 3** shows a forced air heating system that is outfitted with air conditioning.

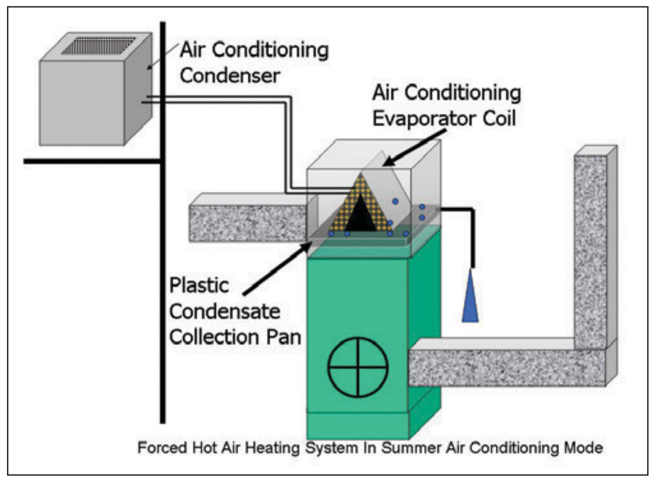


Figure 3
Forced air heating system outfitted with air conditioning.

Air Conditioning Evaporator Coil

The evaporator coil, as shown in **Figure 4,** is mounted in a sheet metal enclosure above or to the side of the furnace in a horizontal application. During summer cooling months, moisture in the circulated air will condense on the evaporator coil where it is collected within a condensate pan and then drained to a suitable disposal location to prevent water contact and damage to the furnace.

Initially, condensate pans under evaporator coils were made of metal; however, due to problems with corrosion, many manufacturers have outfitted evaporator coils with polymer or composite condensate drain pans (as shown in **Figure 5**) in order to eliminate the effects of corrosion.

Figure 4
Evaporator coil.

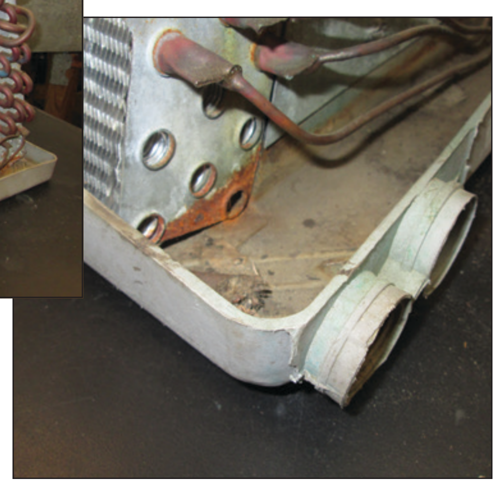


Figure 5
Composite/plastic condensate pan.

Figure 6
Heat-damaged evaporator coil and condensate pan.

Figure 7
Soot damage.

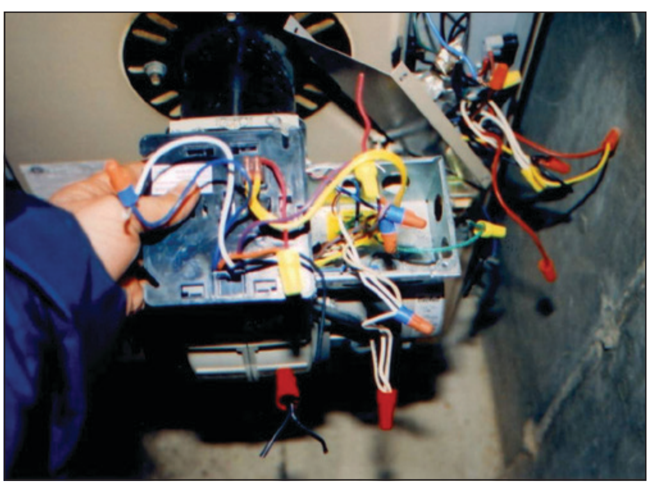


Figure 8
Furnace wiring.

Causes of Evaporator Pan Fires and Runaway Furnaces

Many instances of smoke and fire damage to homes have resulted from overheating furnaces either melting or igniting polymer evaporator coil pans as shown in **Figure 6.** The damage caused by a burning plastic evaporator pan can be extensive, often resulting in smoke and soot damage to the building structure. The melted plastic of the condensate pan may fall into the furnace's heat exchanger and damage the appliance itself, causing it to be replaced.

Fires also result in furnace malfunctions with the level of overheating being so extreme that combustible floor joists above the furnace ignite.

Causes of overheating include:

- Inadequate clearance between furnace/heat exchanger and combustible condensate pan
- Restricted airflow in the recirculation stream
- High limit control failure
- Circulator fan failure
- Improper wiring
- Excessive fuel addition to combustion chamber

Case Study Particulars

This paper focuses on litigation resulting from the malfunction of a new oil-fired forced air furnace installed in the fall of 2005 by a contractor.

In February of 2006, a fire, which was identified as originating within the ductwork of this forced air furnace, occurred at this property. **Figure 7** shows soot damage from the ductwork caused by a burnt evaporator coil pan.

Following the fire, the same company that installed the original furnace removed the fire-damaged appliance and re-installed an identical furnace immediately after the loss.

Fire investigators determined that the furnace wiring had not been preserved after the fire as shown in **Figure 8.** Portions of it were disposed of during the removal and replacement of the fire-damaged appliance.

This investigation provided significant challenges due to spoliation of the evidence.

Investigation Procedures

During the investigation, key variables of the furnace's installation were analyzed to identify potential deficiencies in installation and operation. This included clearance between the heat exchanger and plastic evaporator pan, as well as other conditions previously listed.

Several furnace components were damaged as a result of the fire, including the circulating fan and high temperature control (as seen in **Figure 9**). As a result, pre-fire operability of the furnace could not be determined.

A primary focus in the investigation was the high limit control. The original high limit control was identified as a helical coil type of device inserted into the air stream just downstream from the furnace. Destructive examination of the control commenced by removing the high limit electrical contacts from the control.

Upon examining the contacts, as viewed in **Figure 10,** there was no evidence of any past electrical activity. Accordingly, it did not appear that the high limit control was wired into the control circuit that would have shut the oil burner down in the event of a high temperature.

Testing of an identical "exemplar" control showed that a visible arc overheating of the high temperature control contact was seen after only one cycle of operation. This testing validated the hypothesis that the high limit control was never properly wired into the circuit of the furnace.

Figure 11 shows the contact from the exemplar limit switch.

Wiring Analysis

With the hypothesis apparently confirmed, the next challenge was to determine whether the high limit control was indeed not wired into the circuit, and (if possible) to identify the party responsible for the error in wiring — be that the installer or the manufacturer. The furnace wiring is depicted in **Figure 12.**

Although the furnace had much of its wiring detached and removed when it was detached from the system ductwork and electrical service by the initial contractors, a detailed "as-built" wiring circuit diagram of the existing wires was created (via inspection) and is shown in **Figure 13.**

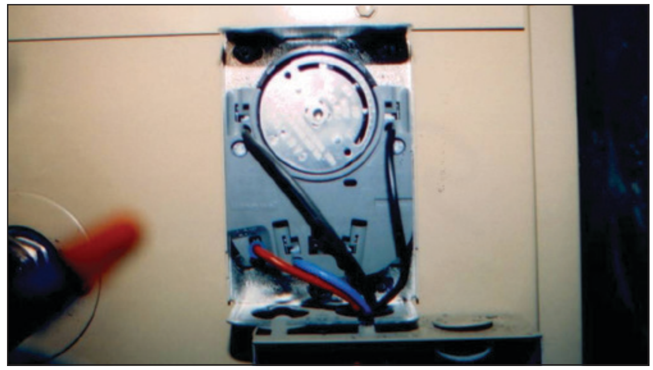


Figure 9
Fan limit and high temperature control into the furnace.

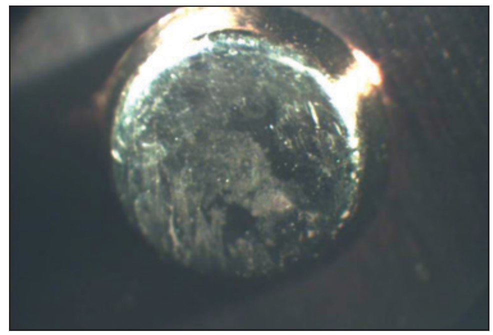


Figure 10
High limit control shows no electrical activity.

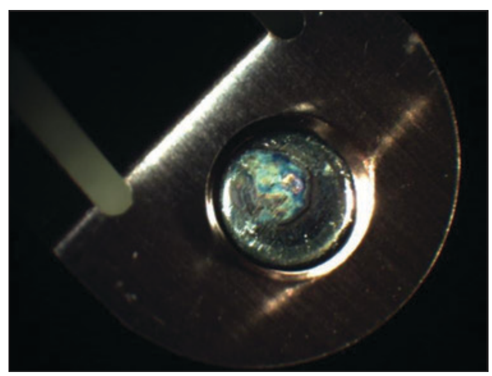


Figure 11
Arcing found on contact of high limit switch that was properly wired into circuit. Compare to contact shown in Figure 10.

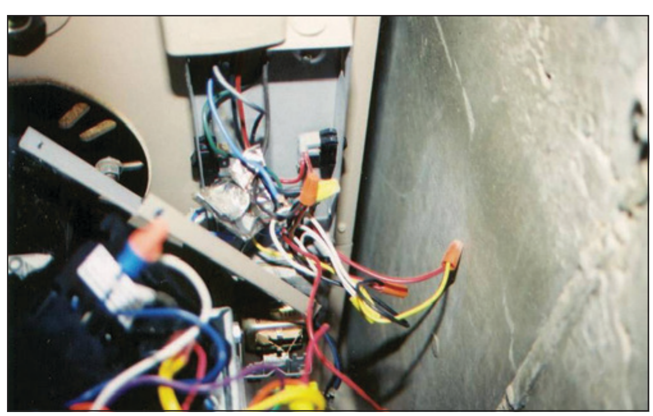


Figure 12
Furnace wiring.

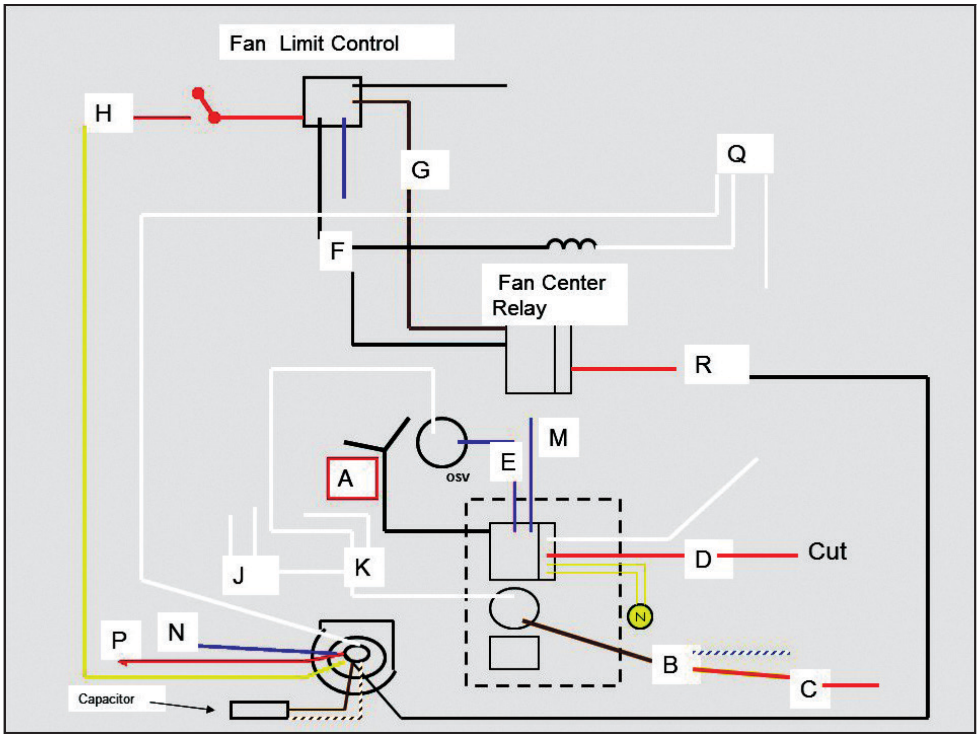


Figure 13
As-built wiring of disassembled furnace.

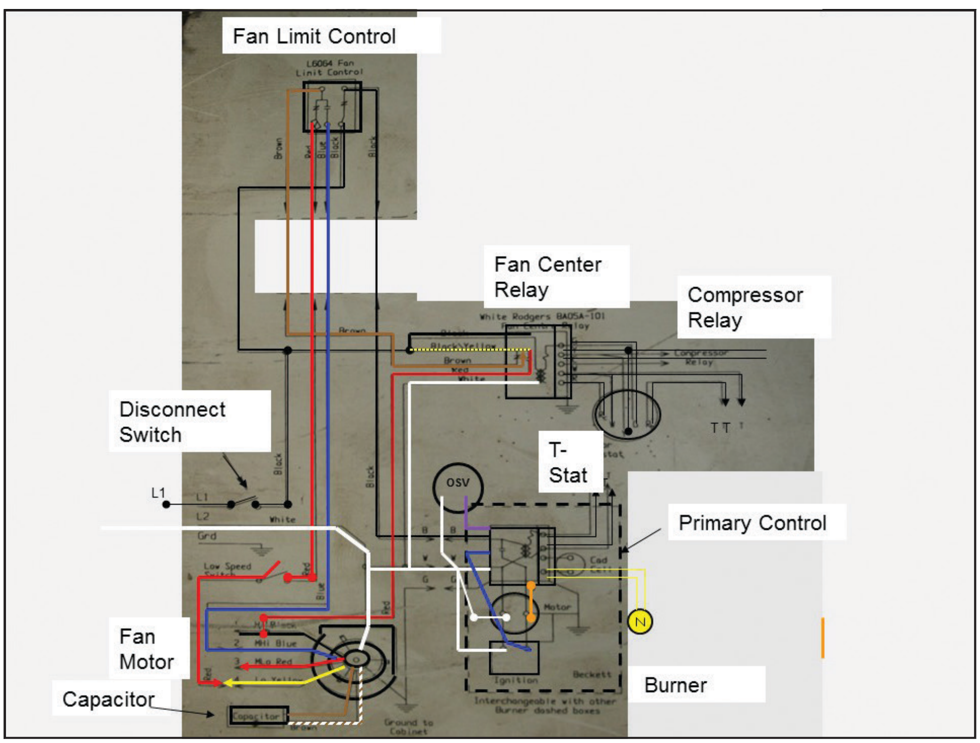


Figure 14
Colored wire lines superimposed over manufacturer's wiring diagram for both furnace and primary high limit control.

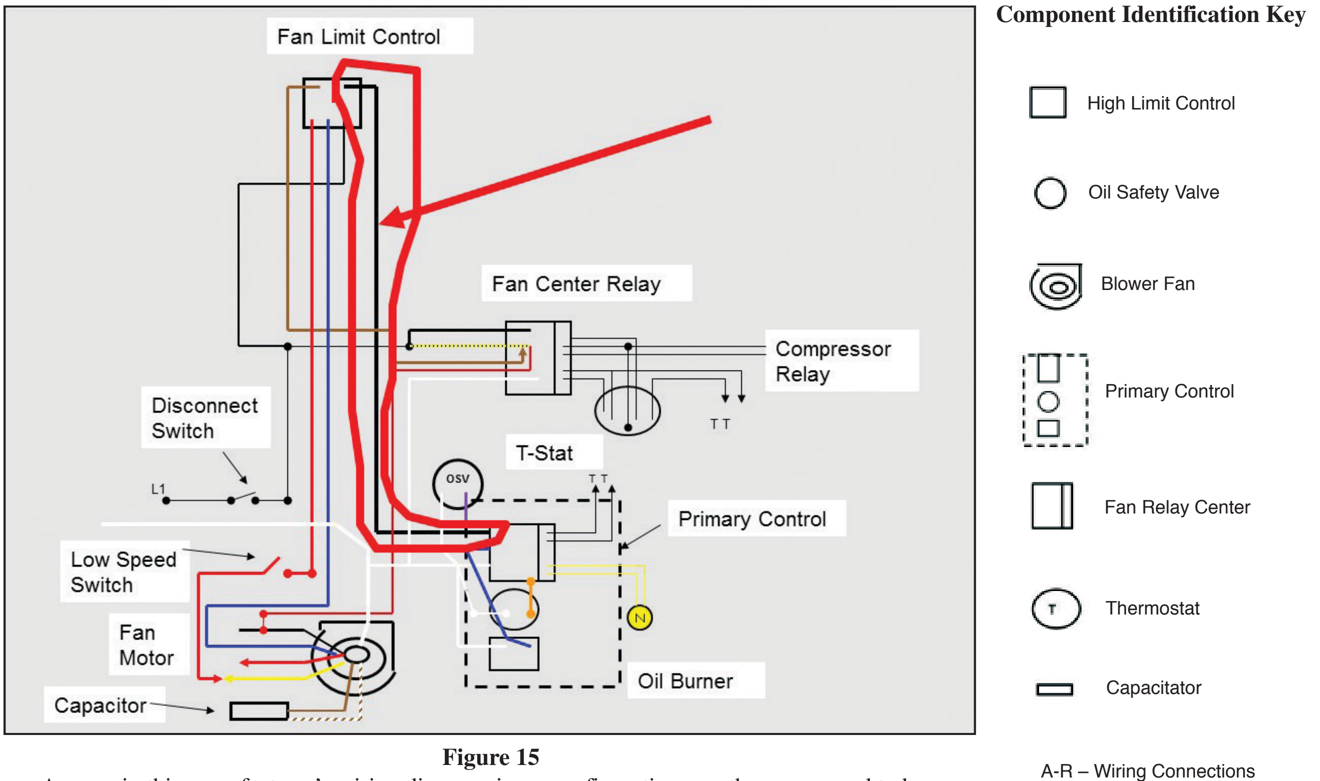


Figure 15
As seen in this manufacturer's wiring diagram, in no configuration was there supposed to be a branch off of the L1 line to the burner.

Where the as-built wiring drawing was the same as the manufacturer's wiring diagram, the as-built wiring circuits were superimposed onto the manufacturer's wiring diagram, as shown in **Figure 14.**

By comparing the as-built wiring on the manufacturer's wiring diagram, deviations between the two could be identified.

After the as-built wiring diagram and the manufacturer's wiring diagram were compared, the investigation identified that there was a parallel circuit from the building's power connection leading into the oil burner that bypassed the high limit control (shown in **Figure 15**).

With this wiring configuration, the furnace burner could be energized upon a call for heat from the thermostat, regardless of the temperature being generated by the burner without the safety feature of the high limit controller. The extra power supply wire is shown in **Figure 16.**

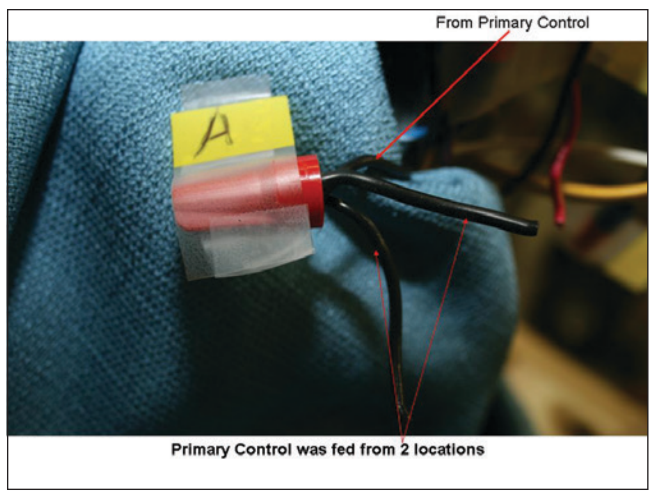


Figure 16
The primary control was fed from two locations, contrary to manufacturer's wiring instructions.

Characteristics of Improper Circuit Wiring

During examination of the identified wire that was a deviation from the manufacturer's wiring (**Figure 17**), the following wire characteristics were identified:

- Number of strands
- Wire gauge
- Type of coating
- Manufacturer's markings

When the factory wiring was compared to the suspect wiring, significant differences (**Figures 18, 19,** and **20**) were noted.

The manufacturer of the furnace was Canadian, and all of the factory-installed wiring was identified as originating from a Canadian supplier. The suspect wiring was identified as originating from a U.S. manufacturer. This same wiring was found in some of the connections of the replacement furnace that was also installed by the same contractor who installed the failed furnace.

It should be noted that upon re-examining the replacement furnace, the same identical error in the wiring was also found. Additionally, conditions were found indicative of the beginning of an overheating condition in the replacement furnace. See **Figure 21** for a comparison of the wiring features.

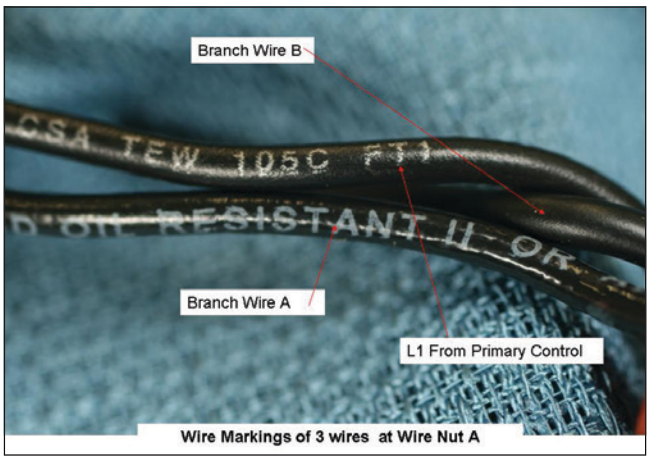
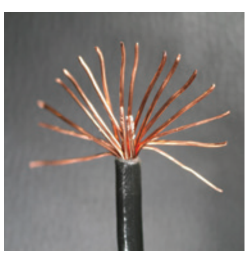
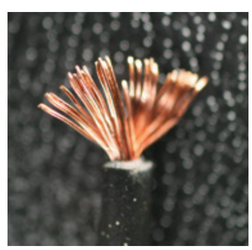


Figure 17
Wire markings of three wires at wire nut A.

	Junction A A Strand	Junction A B Strand	36 Inch Limit L1 Wire
No. Strands	19 - 20	26	24
Coated?	Yes	No	No
Markings	"Markings" Gasoline and oil resistant II or AWM 600 Volt	None	CSA TEW 600V 105C FTI LL 3995 - - - AWM 1015 OR 1230 600V

Appears that coated wires are NOT manufacturers Wiring...

Figure 21
Comparison of wiring features.

			
	Figure 18	**Figure 19**	**Figure 20**
Wire Segment	A	B	36-in. Segment from Limit Switch
No. of Strands	19-20	26	22
Coated	Yes	No	No
Markings	Gasoline & Oil Resistant II or AWM 600 Volt	No Markings	CSATFW 600V 105C FTILL 3995- - - AWM 1015 OR 1230 600V

Conclusion

The procedure used in the investigation not only allowed identification of whether the wiring in this furnace was properly installed, but it also allowed opinions to be drawn regarding the shortcomings of the "as-built" wiring assembly. Examination of the furnace's high temperature control showed that it was not wired properly into the circuit. Therefore, it never functioned properly to control the operation of the furnace. As a result, the furnace operated upon the thermostat's call for heat — regardless of whether or not the temperature generated by the furnace was approaching an unsafe level.

By identifying the characteristics of the materials used in the wiring circuits of this furnace, the forensic engineer was able to identify which wiring circuits were installed by the manufacturer and which were placed by the contractor.

By comparing the as-built wiring to the manufacturer's wiring diagram, the circuit responsible for the malfunction was found. Through the characteristics of the wiring, the forensic engineering team was able to prove with a reasonable degree of engineering certainty the originator of the negligent work. This led to a settlement based on the determination that the cause of the fire was due to improper installation.

The team reconstructed enough of the existing evidence to develop an opinion as to the cause of the loss. This same procedure could potentially be used with other electromechanical equipment.

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