

列车清洗机端刷接近开关电磁干扰原因分析及抑制措施

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摘 要 介绍了苏州轨道交通 5 号线列车清洗机端刷所用接近开关的类型及原理, 分析了影响接近开关正常工作的电磁干扰源, 提出了抑制接近开关电磁干扰的措施: 在接近开关控制回路中增加中间继电器, 在电气柜控制电路中增加隔离变压器和电源滤波器。

关键词 地铁列车; 清洗机; 接近开关; 干扰源; 抑制措施

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Cause Analysis and Countermeasures of Electromagnetic Interference of Proximity Switch in the End Brush System of Metro Train Washing Machine

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Abstract The type and principle of the proximity switch used by the end brushes of Suzhou rail transit metro train washing machine are introduced. The electromagnetic interference sources affecting switch normal operation are analyzed. Measures to suppress the electromagnetic interference of the proximity switch are proposed: adding an intermediate relay to the control loop of the proximity switch, and adding an isolation transformer and a mains filter to the control circuits of the electrical cabinet.

Key words metro train; washing machine; proximity switch; interference source; countermeasure

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接近开关作为一款不需要与设备动作部件发生直接机械接触便可触发其开关动作的高效传感器, 被广泛运用于工业生产和日常生活中。苏州轨道交通 5 号线列车清洗机的端刷洗系统中使用了许多接近开关, 用以进行位置检测与限位保护。端刷洗系统用以刷洗列车首尾两辆车端面, 端刷安装在两侧龙门结构中, 由接近开关限制其摆出、行走和升降的范围^[1]。接近开关可将传感器与物体间的位置关系信息转化为能够被电气系统识别的电信

号^[2]。然而, 5 号线列车清洗机投入使用以来, 端刷接近开关频繁失效, 屡次出现端刷上升超出上限位的故障, 对日常洗车作业造成了一定影响。排除接近开关本身质量问题后, 可断定造成其失效的原因为某种干扰。由于列车清洗机本身以及周围环境组成了一个复杂系统, 所以导致失效的原因可能是某一种或者几种干扰源的共同作用。其中地铁迷流、伺服驱动系统以及高压接触网等系统与环境因素所产生的感应电都会对电力线路造成电磁干扰^[3-5]。本文在阐明 5 号线列车清洗机端刷接近开关原理的基础上, 对上述干扰源的作用原理展开分析, 并提出了为避免干扰所采取的抑制措施。

1 接近开关的类型及原理

接近开关是一类传感器的统称, 可细分为电感式、电容式、霍尔式和磁性式接近开关等^[2]。不同类型接近开关的工作原理甚至作用对象都截然不同。5 号线列车清洗机端刷所使用的接近开关为三线制 PNP(由两块 P 型半导体中间夹着一块 N 型半导体所组成的三极管) 常开型电感式接近开关, 具有短路和过载保护、无剩余电流、低电压降等优点。其感应对象仅限于接近其感应面的金属物体。将接近开关接入电路时, 其中两根线分别接入直流电源正负极, 第三根线用于输出信号, 接入 PLC(可编程逻辑控制器) 的输入端。

三线制 PNP 常开型电感式接近开关主要由振荡器、检测电路和放大输出电路三部分组成。振荡器由线圈和 LC(一个电感和一个电容连接在一起的电路) 振荡电路构成, 位于接近开关内部结构的最前端。振荡器能够在感应面前方形形成一个高频交变电磁场。当列车清洗机的端刷上升时, 其根部的金属片也随之进入接近开关的磁场感应区。此时金属片内部可等效视作无数个圆圈型闭合回路, 由于交变磁场在此闭合回路中的磁通量是不断变化的, 所以在金属片内部就产生了感应电动势和感

应电流,这种现象也被称作涡流效应。

涡流直接导致振荡电路的负载变大,使振荡能力衰弱甚至停止振荡^[6]。振荡电路的这一变化被后置检测电路识别后,常开触点闭合,经过放大输出电路将开关信号输入 PLC。至此端刷接近开关便完成了将端刷上升到位的位置信息转变为能够被 PLC 所识别的电信号的任务。

2 电磁干扰源分析

2.1 高压电网干扰源分析

公共高压电网存在着各种形态且不易被察觉的干扰,干扰的形态可分为低频干扰和高频干扰两类。低频干扰的表现形式有欠压、过压、间断、断电、浪涌和频率漂移等。用电设备的启停引起电网负载的剧烈变化就会产生低频干扰信号。高频干扰的表现形式有毛刺、尖峰和高频谐波等。导致高频干扰信号产生的原因较多,比如用电设备启停的瞬间冲击、电网供电的非线性负载、高频用电设备的反向辐射、自然界中的雷电冲击等。

5 号线采用 DC 1 500 V 架空接触网供电系统为列车提供运行动力,也属于高电压强电流等级范围。在列车清洗机主库内,列车同样采用此供电方式。接触网带电导线包括接触线、承力索、回流线和正馈线等,当强电流通过接触网带电导线时,电能不断地向列车和空气中传播,造成带电导线内部电流处于不平衡状态,接触线与大地之间产生一个等同于操作电压的电位差,于是在接触网的周围便产生了电磁场^[7]。周围电气设备在此电磁场中遭受不同程度的电磁干扰。磁场强度与到接触线的距离成反比,距离越远磁场强度越小。列车清洗机端刷升降限位接近开关距离接触线较远,此处磁场强度较小;端刷升降上限位接近开关距离接触线较近,此处磁场强度较大。

2.2 伺服驱动器输出电压干扰源分析

列车清洗机端刷的升降和行走动作都是依靠伺服系统来进行定位控制的。伺服驱动器和伺服电机是伺服系统的重要组成部分。伺服驱动器安装在辅库电气柜内,而伺服电机同接近开关一样,直接安装在端刷龙门架内。伺服驱动器的通信接口连接 PLC 的输出端,通过接收 PLC 发出脉冲的频率和数量来控制伺服电机运行的距离和速度。伺服驱动器并非直接将来自 PLC 的脉冲信号方波简单放大,而是通过脉冲宽度调制的方式模拟输出

正弦波。伺服电机中的转子受电压信号控制得以实现正反转。当端刷接近开关触发时,伺服驱动器输出信号电压变为零,伺服电机停止旋转,端刷到位停止。在日常端洗作业中,伺服驱动器需要不断调整输出电压以完成端刷的各项动作,保证前后端洗能够正常进行。因此在伺服电机频繁启停与正反转的过程中,伺服驱动器的输出电压也在不断变化,导致在伺服电机周围的导体中容易产生感应电动势。此感应电动势对端刷接近开关造成了一定的电磁干扰。

2.3 地铁迷流干扰源分析

地铁迷流是列车运行时泄露到道床与周围大地土壤介质中的杂散电流,产生于列车接触网直流牵引供电回路的回流。5 号线列车就采用直流电力牵引方式,将受电弓作为正极连接接触网,轮下走行轨道作为负极回流导线。由于走行轨存在较大电阻,导致牵引电流在回流时容易产生压降,同时走行轨与大地间也存在着电位差,为地铁迷流的产生创造了必要条件。不过在正常轨道段落,走行轨与道床之间的绝缘程度其实非常高,能够有效减少流入土壤介质中的迷流。然而,每次洗车作业结束后,主库内都非常潮湿,轨道附近也会残留积水,不可避免地会造成走行轨与道床之间的绝缘性能逐渐降低,洗车作业时流入土壤介质中的迷流也逐渐增多。杂乱无序的迷流从道床向四周扩散,其中一部分流入了地下埋设的金属管道和沿轨道铺设的金属结构中。迷流在金属导体周围形成紊乱复杂且不停变化的电磁场,严重干扰端刷接近开关对金属物体的识别。迷流甚至会流进电气设备的接地端,引起局部接地电位过高,从而影响电气设备正常工作。此外,地铁迷流还会对金属管线、金属构件和道床内的结构钢筋等导体造成电化学腐蚀,严重损害设备的使用寿命,存在一定程度的安全隐患。

3 抑制电磁干扰措施

3.1 增加中间继电器

为了减少各因素对接近开关输出信号的干扰,采取在控制回路中增加中间继电器的措施,将中间继电器的常开触点两端分别连接电源线和 PLC 输入端,将中间继电器的线圈两端分别连接电源线和接近开关输出信号线(见图 1)。当端刷摆出至接近开关触发时,接近开关的输出信号使中间继电器的线圈得电,常开触点吸合,于是 PLC 输入端得电,输

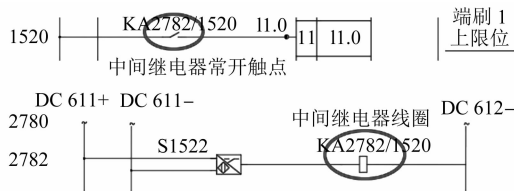


图 1 增加中间继电器后的接近开关控制电路

Fig. 1 Circuit diagram of proximity switch after adding an intermediate relay

出脉冲信号通过伺服驱动器控制伺服电机到位停止。如此原本一个控制回路被中间继电器分隔为两个控制回路,使电磁干扰仅存在于线圈侧回路

中,而不会对触点侧的 PLC 输入信号产生影响,在不改变接近开关功能的情况下可有效阻隔电磁干扰。同时,中间继电器的线圈是有电阻的,用接近开关输出信号线连接中间继电器线圈相当于串联一个小型电阻,同样可以减小接近开关受到电磁干扰的影响。

3.2 增加隔离变压器和电源滤波器

在电气柜控制电路中增加隔离变压器和电源滤波器。将隔离变压器和电源滤波器连接在控制回路电源与断路器 KM118 的常开触点之间,如图 2 所示。

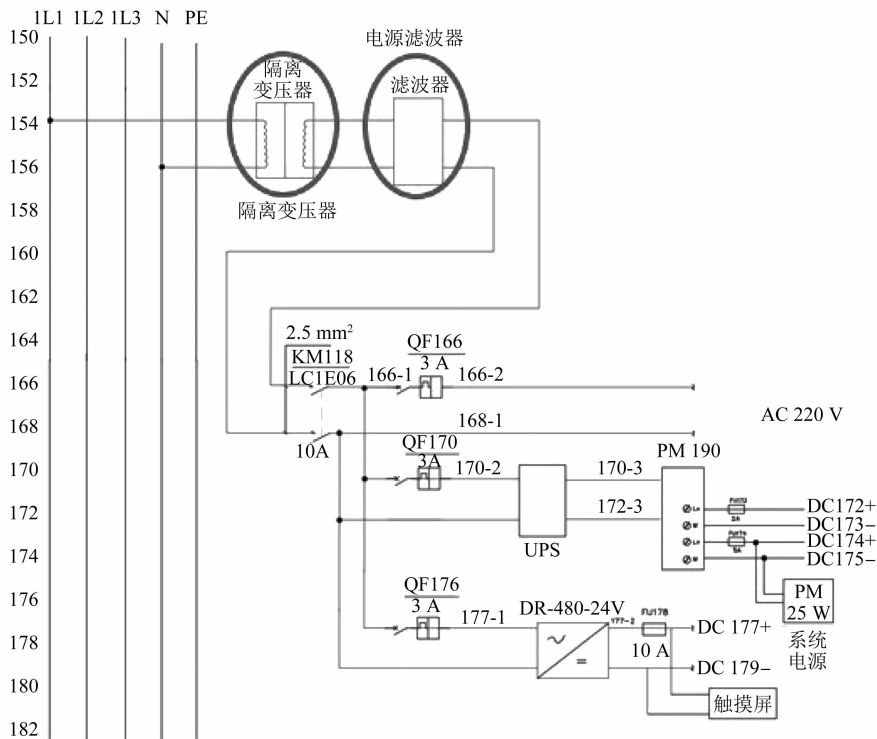


图2 增加隔离变压器和电源滤波器后的电气柜控制电路图

Fig. 2 Circuit diagram of the electrical cabinet after adding an isolation transformer and a mains filter

隔离变压器的输入线圈绕组与输出线圈绕组在电气上彼此完全隔离,仅通过电磁感应原理实现在输出线圈绕组两端产生电压,其电压变比为1:1,不会改变后级电路的电压大小。隔离变压器线圈绕组中的铁芯具有高频损耗大的特点,对输入端起到了良好的过滤作用,即抑制高频谐波从主电源传入控制回路,降低电源电网对控制回路的干扰。与此相对应,控制回路中用电设备产生的干扰也不会传入主电源电路。

电源滤波器通过对其输入、输出端的阻抗和电源及负载的阻抗进行适配,滤除电源线中某些不需

要的特定频率的谐波。将隔离变压器和电源滤波器组合使用,前者隔离掉电源线中的高频谐波,后者再对其他频率的谐波进行滤除,如此可大幅衰减控制回路中来自电源的电磁干扰,从而使接近开关得到稳定的正弦波电源信号。

4 结语

接近开关虽然只是列车清洗机中一个极小的组成部分,但是却直接影响着整个列车清洗机能否正常运行。前后端洗是洗车作业中最重要的两项工序,如果端刷接近开关出现故障失效,不仅洗车

作业必须被迫终止,甚至可能会导致端刷失控,对电客车造成伤害。苏州轨道交通 5 号线列车清洗机在采取了增加中间继电器、增加隔离变压器和电源滤波器等措施后,端刷接近开关干扰问题得到了有效地解决,未再出现端刷上升超出上限位的故障,其他动作机构的接近开关也维持在正常工作状态,无任何异常。

由此可见,只有采取有效的抑制干扰措施,切实防范高压电网、伺服驱动器的输出电压和地铁迷流等电磁干扰,才能让接近开关稳定正常地工作,保证洗车作业安全、有序和高效地进行。

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苏州轨道交通将迎来“环线时代”

日前,苏州轨道交通 8 号线中塘公园站至车斜路站盾构区间左线隧道顺利贯通。8 号线起于西津桥站,主要经过苏州高新区、姑苏区、相城区和苏州工业园区,止于车坊站,共设车站 28 座,全长 35.5 km,是古城外围从西北到东南的骨干线路、湖东地区的南北向骨干线。预计 2024 年 9 月投入运营的 8 号线,届时将与已投运的 3 号线在线网中构成“组合环”,打造苏州轨道交通的“环线时代”。此次贯通的左线隧道全长 1 505 m,施工过程中依次下穿中塘河、国家电网变电站、在建 6 号线和斜塘河桥等构筑物。施工人员表示:“在中塘河河底下方施工,就像在‘果冻里打洞’,施工过程中必须小心翼翼。盾构施工对土压的要求、土壤改良效果要求极高,稍有不慎就会导致河底击穿、盾尾渗漏等后果。”

近日,苏州轨道交通 6 号线星海街站至李公堤西站区间右线也已顺利贯通。6 号线是苏州市连接高新区、姑苏区、工业园区和吴中区的重要干线枢纽,全长 36.12 km,共设车站 31 座,计划于 2024 年 6 月试运营。6 号线建成后将进一步强化金鸡湖两岸的联系,也将成为城市东西向穿越古城及金鸡湖的重要客流通道,对促进苏州新老区经济互融有着重要意义。

苏州轨道交通 7 号线也传来好消息。林家潭路站主体结构于 5 月 22 日顺利封顶,正式进入盾构施工阶段。7 号线全长 29.6 km,共设车站 25 座,均为地下站。目前,全线正在进行车站主体结构施工和区间盾构施工,计划于 2024 年 12 月开通初期运营。建成后,7 号线将与 4 号线支线贯通,届时线路总里程达 40.4 km,共设车站 33 座。7 号线为城市南北向骨干线路,是古城东侧重要的南北客流通道,强化了湖西核心区与高铁新城的联系,也是高铁苏州北站客流的重要集散线路。

也就是说,预计 2024 年 6 至 12 月,苏州又将新添 3 条轨道交通线路,加上已有的 1 号线、2 号线、4 号线及支线,3 号线、5 号线,苏州市民的出行肯定会越来越便利。

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(Continued from Commentary)

ban line and suburban line. Until now, Suzhou has started operation of 5 lines, with operation mileage of 210 km and another 161.4 km undergoing construction. A growing vision is deeply perceived that rail transit not only plays a major role of urban rail transit ‘main force’, but also affords historical responsibility in riding the wave of green low-carbonization, urban renewal and intelligent interoperation.

Respect Life, Value Safety. Since 2007, Suzhou has approved three rounds and total nine lines of construction and planning, in the 15 years of which, considering the city’s special geological environment and necessity of ancient city protection, with reference to the world-class construction standard, Suzhou Rail Transit has proactively explored technological innovation paths, and has successfully formulated a serious of ‘Suzhou experience’ including ‘four instruments’ for civil engineering, standardized management, smart construction site, unmanned driving technology application, industrial personnel livelihood, winning ‘National High-quality Engineering Award’ and ‘Tien-Yow Jeme Civil Engineering Award’ and keeping record of 0 safety accident at large grade or above.

Elegant Jiangnan, Exquisite Service. Over a decade of operation, Suzhou Rail Transit has been continuously optimizing operation organization, elevating service level, and fulfilling the resident’s growing expectation of living standard. In Suzhou, the first domestic ‘unconditional refund’, 24-hour operation on major holidays, the first provincial ‘strong-weak air-conditioned compartments’ were published, achieving passenger satisfaction growth of 9 years in a row. Suzhou Rail Transit is also the first promoting audio program of ‘Metro & Poem’ and pocket book ‘Metro & Tour’, coming up with the first domestic scenario cultural tourism specialized route, the Suzhou ‘underground city’ is becoming readable, warm and sympathetic.

During the ‘14th Five-Year Plan’ period, according to the deployment noted in Transportation Power and ‘Outline of Smart Urban Rail Implementation’, centering the new positioning of ‘regional integration pioneer, old city pump of fresh energy’, Suzhou Rail Transit is implementing the 3 strategies of ‘4-network integration, station-city integration, digitalized integration’, constructing the business layout of ‘construction, operation, resource development, industrial investment 4 in 1’, advancing towards the goal of ‘comprehensive, green, safe, smart’ three-dimensional modern urban transportation.

Forge ‘Suzhou Template’ of ‘4-network Integration’. Taking advantage of Transportation Power, Yangtze River Delta integrated development and suburban integrated development, Suzhou Rail Transit constructs a rail transit ‘complete network’ of ‘covering city, connecting suburban, channeling intercity, linking national railway’, from the aspects of functionality integration, space integration, hub integration, time-sequence integration. Based on existing Line 1 to 8 and S1, the close connection between city center and surrounding counties, or among counties is further promoted. Network of ‘cross-express+center-radiation’ with core of city downtown is constructed, and support for downtown development is reinforced. Total mileage will reach 1 080 km by 2035.

Sketch ‘Suzhou Path’ of ‘Station-City Integration’. TOD (transit-oriented development) is the direction for future urban development. In July 2021, Suzhou issued the Implementation Opinion on Advancing Comprehensive Exploitation and Utilization of Suzhou Rail Transit Station and Surrounding Land, Suzhou Rail Transit thus prompt TOD development projects. Guided by public transportation, taking urban integration as goal, Suzhou Rail Transit takes the 4-step of strategizing, mapping, planning, devising, to comprehensively proceed ‘station-city integration’ TOD development, fully exerting the demonstration influence and effortlessly building ‘point-line-plane’ scale benefit. A layout of high industry and space compatibility, synergistic development of business and charity is formed. The connection and fusion of rail transit and urban space are enhanced wholesome.

Explore ‘Suzhou Scheme’ of ‘Digital Integration’. From the 4 aspects of smart design, smart construction, smart operation and maintenance, and asset management, Suzhou Rail Transit initiates enterprise digital transformation with the core of data standardization, platform integration, engineering digitalization. Currently, BIM (building information model) synergistic management platform and deepening application system is advocated on projects undergoing construction. Operating lines are carrying out smart service terminal upgrading and smart customer service. At the same time, by fully utilizing technologies including BIM, 5G+, AR, VR, cloud computing, the links of design, construction, operation, and asset development are interoperated on digital level, forming fully digitalized life cycle of engineering construction in real sense.

Building metro is building cities. On the 11th conference of Central Leading Group for Financial and Economic Affairs on 26th April, General Secretary Xi emphasizes again that infrastructure is the major support for economic society development, for developing suburban railway and urban rail transit, and for promoting construction of urban comprehensive road transportation system. Suzhou Rail Transit insists on the development guidance of centering residents. Through constant optimization of infrastructure layout, structure, functionality, and development pattern, positioning on the scientific development, strengthening regeneration capability, overall planning development safety, Suzhou Rail Transit is striving for a new era with high spirit, on the journey of manifesting engaging life expectation.

(Translated by ZHANG Liman)