Analysis on the Reliability of Comprehensive Improvement of Electrical-Mechanical Engineering’s Testing Conclusion

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Abstract

By using Taguchi method, some issues affecting the reliability of objective conclusions of electrical-mechanical engineering during its planning, choosing and sampling are analyzed. Also, the system error in the sampling process is quantitatively evaluated. Meanwhile, efficiency factors such as work time and accuracy factors such as sampling probability and sampling error are figured out to describe its composition and comprehensive stabilization methods. And beneficial discussion has been done in order to evaluate the reliability of electrical-mechanical engineering testing results.

Keywords
Testing Program, Taguchi Method, Sampling Error

对综合提高机电工程检测结论可靠性的分析

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摘要
本文利用田口玄一正交法，对某一机电工程检测案例的计划、筛选、抽样等环节影响客观结论可信性的问题进行了分析推导，并对抽样过程中存在的系统误差程度做出定量评测；同时，分别以工作时长代表的效率因素，以抽样概率和抽样误差为代表的准确度因素，通过数理统计，阐述其组成及综合平抑的方法，为评估机电工程检测结论的可靠性进行了有益探讨。

关键词
检测方案，田口正交法，抽样误差

1. 概述
目前针对交通机电工程检测方案，尤其是面向网络结构系统，一般仅关注抽样比率及随机抽取方法，而对其效率和误差指标的研究却很少涉及；因此，确认最终检测结论的准确性与合理性仍有相当多的疑问亟待澄清。

本文通过一个简化版的13站点区域性环网系统，以每个站点的设施为检测组群，这些设备可以是通信系统或监控系统的路侧设备集中点，还可以是收费系统的闸口设备等。利用田口玄一正交法[1]分析各种检测方案的筛选过程以及相应效率的评估取舍。

2. 田口正交法分析
下图1为本文所举案例的设施分布示意，自编号A至N共有13个区域站位，设置有直通和互通两种类型；站位之间标注的数字代表相邻的距离，以均匀行程时间(分钟)衡量。依据《公路工程质量检验评定标准》[1]抽样不低于10%的规则，本案例中同时设置15%和0%（即该点不检测）共计3个等级水平作为调控参数。从而，进行本案例分析时的期望目标为10%的抽样比；希望最小化检测工作时长，期望能尽量压缩不必要的时间消耗；进而在满足规则要求的前提下，充分提高检测效率，并且通过判别相关结论的误差百分比，确认最优选择的可信性。

计算各种情况所需平均时长为：
① 直通站（Z型）进出费时4分钟，抽样率15%；
② 水平检测耗时45分钟，抽样率15%；
③ 水平检测耗时30分钟，抽样率10%；
④ 不检测，抽样率0%。

当只有一个工作组投入检测时，按照最短路径选择排列顺序，将各种最短路径统计于下表，从表1中可以看出，N端站点共有9次被选作起讫点，是此次任务的关键节点位置，若在实际计划时，则应是检测组住宿和内业工作的首选场所。

鉴于上述情况，选择采用田口正交法\(L_27(3^3)\)表进行统计分析。利用该表只需进行27次有效观察，就能代表具有13个因素（站位数），每因素含有3水平（三种抽样概率）组合成的1,594,323次普通推算可能。将表1数据代入表2计算。
图 1. 机电工程检测站点分布示意图

Table 1. 单任务最短路径汇总表

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</table>
根据表 2 的计算结果分析如下:

(1) 13 个站点因素平均值的极差都是 15 分钟, 这说明站点之间不存在特别差异, 对检测结果的影响是均衡的, 因此可以任选其一作为系统的代表样进行检测。

(2) 27 次推算结果的时长极差为 726 分钟, 表明抵达不同站点的路径与该站点抽样率所构成的组合影响显著; 即, 站点位置和检测时间很重要。

(3) 方案 1 是对 100% 站点进行全部 15% 的抽样检测, 其时长和抽样误差百分率分别为 19.9% 和 0%, 但费时最久 (1004 分钟); 而方案 3 虽然时长 (278 分钟) 最短, 但误差较高; 所以这两个方案一般不予考虑。

(4) 通过比选, 方案 4 作为首选, 其检测时长 686 分钟, 时长误差 19.7%, 抽样误差 62.0%: 方案 2 作为次选, 其检测时长 869 分钟, 时长误差 21.7%, 抽样误差 20.9%。

(5) 综合上述分析, 推荐方案 4, 其抽样概率为 9.2%, 接近 10% 的期望目标。该检测方案类型为: A_1B_2C_2D_2E_1F_1G_1H_2J_2K_2L_3M_3N_3, 即第 1 和第 5~7 共 4 个站进行 15% 的抽样, 第 2~4 和第 8~10 共 6 个站进

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极差: \( R = 1004 - 278 = 726 \) 分钟
抽样率: \( \sigma/\lambda = 2.4% \)
方案 2

\[ \frac{\sigma}{\gamma} = 5.7% \]
行 10% 的抽样，第 11~13 计有 3 个不检测。按照单行程 A-B-C-D-E-F-G-H-E-J-K-L-C-M-G-H-E-N 路径进行框算，总时长近似为 $686 \times (878/1004) = 600$ 分钟（约 10 小时），比原始估算时间（约 15 小时）缩短了 1/3。方案 2 的抽样率达到 11.5%，且误差较小，但检测时长和误差均低于方案 4 的指标。因此，基于效率和准确度平衡的角度，以方案 4 为优选，方案 2 作为备选。

3. 抽样误差分析

按照《公路工程质量检验评定标准》[2]要求，机电系统关键项合格率为 100%，次要项目合格率达到 90% 以上，现场抽样数不应少于 3 个。

按不重复抽样公式计算如下：

$$
\mu_s = \sqrt{\frac{\sigma^2}{n} \left( \frac{N-n}{N-1} \right)}
$$

其中 $\sigma$ 为总体标准差，此处以样本标准差代替（设为 2.4%），那么，当 $N$ 值很大时，计算公式可近似为：

$$
\mu_p = \sqrt{\frac{\sigma^2}{n} \left( 1 - \frac{n}{N} \right)}
$$

其中：标准差 $\sigma$ 设为 2.4%，$n$ 为抽取个数（设为 3 个），$n/N$ 为抽样比率（设为 11.5%），代入计算：

$$
\mu_p = \sqrt{\frac{0.024^2}{3 \times 13} \left( 1 - 11.5\% \right)} = 0.4\%
$$

因此，当每站点抽检不少于 3 组套设备时，依据前面案例分析数据的结论，其中备选方案 2 的随机抽样误差为 0.4%；优选方案 4 的误差为 1.0%。其他各组如下表 3。

按照不重复抽样条件，针对期望目标为总体不低于 10% 抽样率的各类型方案误差均很低，系统误差很小，完全能够达到现场控制质量的目标，并且随着抽样数量的增加，相应的误差会更加趋向减小。

4. 结语

经上述案例分析，能系统地证明，按照《公路工程质量检验评定标准》[2]要求，即便采取较高风险的小比率抽样方式，但通过对检测方案的计划、筛选、抽样频次等因素的高效组织，同样能够极大地改善检验结果的准确度和效率。

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<th>序号</th>
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<th>$n$</th>
<th>$\mu_p$</th>
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<td>$3 \times 13$</td>
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<td>6.5%</td>
<td>7.7%</td>
<td>$3 \times 8$</td>
<td>1.3%</td>
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</table>
因此说，任何节省成本的努力都必须基于科学严谨的方案设计；并且，当能够有效地控制客观误差，也就可以确保检测结论的可靠性。

参考文献（References）