磁通门经纬仪校准试验报告

1. 概述

2019年9月，由中国地震局地球物理研究所组织，在陕西乾陵地磁台开展了全国地磁基准台网DI仪（磁通门经纬仪）比测工作，全国41个基准地磁台的工作人员现场参与了此次工作，比对测量以乾陵地磁台磁通门经纬仪测试结果为标准参考值，并对兰州台等6个台站的仪器进行了试验性的校准测试，对各项结果进行了不确定度评定，经专家及各台站工作人员分析，校准结果符合仪器特性，其中不确定度的评定对仪器性能、测量环境及测量过程的判断起到了辅助作用。

1. 基本情况

测试时间：2019年9月

测试地点：陕西省地震局乾陵地磁台

测试人员：标准测量：古云飞 李西京 黄好；被校仪器：各台测量员

标准仪器：Mingeo 010A (No.807282)

测试环境：温度：27.0℃；相对湿度：45%RH ；干扰磁场小于0.5nT

1. 测试内容

2.1 兰州台Mingeo型磁通门经纬仪校准记录及结果

表1 磁通门经纬仪装置参数及仪器偏移记录表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 观测仪器 | 组别 | *D*基线值(′) | *I*基线值(′) | 水平夹角  (′) | 垂直夹角  (′) | 零点偏移  (nT) |
| 参考仪器 | I | 21386.89 | 3198.63 |  |  |  |
| II | 21386.89 | 3198.64 |  |  |  |
|  | III | 21386.86 | 3198.62 |  |  |  |
| 兰州Mingeo  No.091701 | 1 | 21386.89 | 3198.57 | -0.63 | -0.74 | 8.68 |
| 2 | 21386.86 | 3198.55 | -0.60 | -0.75 | 8.80 |
| 3 | 21386.83 | 3198.56 | -0.59 | -0.78 | 8.53 |
| 4 | 21386.86 | 3198.57 | -0.58 | -0.76 | 8.14 |
| 5 | 21386.89 | 3198.59 | -0.58 | -0.77 | 8.62 |
| 6 | 21386.85 | 3198.59 | -0.60 | -0.77 | 8.68 |
| 参考仪器 | IV | 21386.90 | 3198.63 |  |  |  |
| V | 21386.88 | 3198.64 |  |  |  |
| VI | 21386.89 | 3198.64 |  |  |  |
| 参考仪器 | 平均 | |  | | --- | | 21386.89 | | |  | | --- | | 3198.63 | |  |  |  |
| 兰州Mingeo  No.091701 | 平均 | |  | | --- | | 21386.86 | | |  | | --- | | 3198.57 | | -0.60 | -0.76 | 8.58 |
| 精密度 | |  | | --- | | 0.020 | | |  | | --- | | 0.010 | |  |  |  |
| 仪器偏移 | -0.030 | -0.060 |  |  |  |

表2.1 磁通门经纬仪修正系数观测记录表（第1页）

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *F*/nT | ±*β* | | 垂直度盘读数 | | | 磁强计输出 | 修正系数 |
| ′ | rad |
| 52860 |  | 0 | 127 | 15 | 0 | 0.8 | 0.98098 |
| 52860 | 4 | 0.001163553 | 127 | 19 | 0 | 64.0 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.1 |
| 52860 | -4 | -0.001163553 | 127 | 11 | 0 | -61.1 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.4 | 0.98472 |
| 52860 | 5 | 0.001454441 | 127 | 20 | 0 | 79.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.3 |
| 52860 | -5 | -0.001454441 | 127 | 10 | 0 | -77.1 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.1 | 0.98998 |
| 52860 | 6 | 0.001745329 | 127 | 21 | 0 | 93.7 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.6 |
| 52860 | -6 | -0.001745329 | 127 | 9 | 0 | -92.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.1 | 0.98866 |
| 52860 | 7 | 0.002036217 | 127 | 22 | 0 | 112.0 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.5 |
| 52860 | -7 | -0.002036217 | 127 | 8 | 0 | -105.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.4 | 0.98414 |
| 52860 | 8 | 0.002327106 | 127 | 23 | 0 | 126.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.8 |
| 52860 | -8 | -0.002327106 | 127 | 7 | 0 | -124.4 |
| 52860 |  | 0 | 127 | 15 | 0 | 1.2 | 0.9876 |
| 52860 | 9 | 0.002617994 | 127 | 24 | 0 | 140.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 0.3 |
| 52860 | -9 | -0.002617994 | 127 | 6 | 0 | -140.1 |
| 52860 |  | 0 | 127 | 15 | 0 | 0.3 | 0.98488 |
| 52860 | 10 | 0.002908882 | 127 | 25 | 0 | 156.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 0.6 |
| 52860 | -10 | -0.002908882 | 127 | 5 | 0 | -155.3 |
| 52860 |  | 0 | 127 | 15 | 0 | 0.6 |

表2.2 磁通门经纬仪修正系数观测记录表（第2页）

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *F*/nT | ±*β* | | 垂直度盘读数 | | | 磁强计输出 | 修正系数 |
| ′ | rad |
| 52860 |  | 0 | 127 | 15 | 0 | 1.9 | 0.98851 |
| 52860 | 4 | 0.001163553 | 127 | 19 | 0 | 63.7 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.1 |
| 52860 | -4 | -0.001163553 | 127 | 11 | 0 | -60.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.2 | 0.98315 |
| 52860 | 5 | 0.001454441 | 127 | 20 | 0 | 80.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 2.6 |
| 52860 | -5 | -0.001454441 | 127 | 10 | 0 | -75 |
| 52860 |  | 0 | 127 | 15 | 0 | 3.4 | 0.98779 |
| 52860 | 6 | 0.001745329 | 127 | 21 | 0 | 96.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 3.5 |
| 52860 | -6 | -0.001745329 | 127 | 9 | 0 | -90.3 |
| 52860 |  | 0 | 127 | 15 | 0 | 3.4 | 0.9902 |
| 52860 | 7 | 0.002036217 | 127 | 22 | 0 | 112.0 |
| 52860 |  | 0 | 127 | 15 | 0 | 3.8 |
| 52860 | -7 | -0.002036217 | 127 | 8 | 0 | -105.0 |
| 52860 |  | 0 | 127 | 15 | 0 | 4.2 | 0.98331 |
| 52860 | 8 | 0.002327106 | 127 | 23 | 0 | 130.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 5.4 |
| 52860 | -8 | -0.002327106 | 127 | 7 | 0 | -118.9 |
| 52860 |  | 0 | 127 | 15 | 0 | 6.4 | 0.98901 |
| 52860 | 9 | 0.002617994 | 127 | 24 | 0 | 146.4 |
| 52860 |  | 0 | 127 | 15 | 0 | 6.7 |
| 52860 | -9 | -0.002617994 | 127 | 6 | 0 | -133.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 6.9 | 0.98678 |
| 52860 | 10 | 0.002908882 | 127 | 25 | 0 | 163.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 7.5 |
| 52860 | -10 | -0.002908882 | 127 | 5 | 0 | -147.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 7.6 |

表2.3 磁通门经纬仪修正系数观测记录表（第3页）

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *F*/nT | ±*β* | | 垂直度盘读数 | | | 磁强计输出 | 修正系数 |
| ′ | rad |
| 52860 |  | 0 | 127 | 15 | 0 | 7.7 | 0.98533 |
| 52860 | 4 | 0.001163553 | 127 | 19 | 0 | 69.7 |
| 52860 |  | 0 | 127 | 15 | 0 | 7.8 |
| 52860 | -4 | -0.001163553 | 127 | 11 | 0 | -55.1 |
| 52860 |  | 0 | 127 | 15 | 0 | 7.8 | 0.98475 |
| 52860 | 5 | 0.001454441 | 127 | 20 | 0 | 85.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.0 |
| 52860 | -5 | -0.001454441 | 127 | 10 | 0 | -70.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.1 | 0.98804 |
| 52860 | 6 | 0.001745329 | 127 | 21 | 0 | 101.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.5 |
| 52860 | -6 | -0.001745329 | 127 | 9 | 0 | -84.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.8 | 0.98749 |
| 52860 | 7 | 0.002036217 | 127 | 22 | 0 | 117.4 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.9 |
| 52860 | -7 | -0.002036217 | 127 | 8 | 0 | -100.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.0 | 0.98252 |
| 52860 | 8 | 0.002327106 | 127 | 23 | 0 | 134.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.9 |
| 52860 | -8 | -0.002327106 | 127 | 7 | 0 | -116.0 |
| 52860 |  | 0 | 127 | 15 | 0 | 8.8 | 0.98760 |
| 52860 | 9 | 0.002617994 | 127 | 24 | 0 | 148.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.0 |
| 52860 | -9 | -0.002617994 | 127 | 6 | 0 | -131.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.3 | 0.99122 |
| 52860 | 10 | 0.002908882 | 127 | 25 | 0 | 164.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.4 |
| 52860 | -10 | -0.002908882 | 127 | 5 | 0 | -145.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.6 |

表2.4 磁通门经纬仪修正系数观测记录表（第4页）

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *F*/nT | ±*β* | | 垂直度盘读数 | | | 磁强计输出 | 修正系数 |
| ′ | rad |
| 52860 |  | 0 | 127 | 15 | 0 | 9.6 | 0.98925 |
| 52860 | 4 | 0.001163553 | 127 | 19 | 0 | 71.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.8 |
| 52860 | -4 | -0.001163553 | 127 | 11 | 0 | -52.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 10.1 | 0.98853 |
| 52860 | 5 | 0.001454441 | 127 | 20 | 0 | 87.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.9 |
| 52860 | -5 | -0.001454441 | 127 | 10 | 0 | -68.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 9.8 | 0.98991 |
| 52860 | 6 | 0.001745329 | 127 | 21 | 0 | 102.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 10.2 |
| 52860 | -6 | -0.001745329 | 127 | 9 | 0 | -83.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 10.6 | 0.99170 |
| 52860 | 7 | 0.002036217 | 127 | 22 | 0 | 118.1 |
| 52860 |  | 0 | 127 | 15 | 0 | 11.0 |
| 52860 | -7 | -0.002036217 | 127 | 8 | 0 | -98.5 |
| 52860 |  | 0 | 127 | 15 | 0 | 11.6 | 0.98370 |
| 52860 | 8 | 0.002327106 | 127 | 23 | 0 | 136.6 |
| 52860 |  | 0 | 127 | 15 | 0 | 11.9 |
| 52860 | -8 | -0.002327106 | 127 | 7 | 0 | -113.2 |
| 52860 |  | 0 | 127 | 15 | 0 | 12.2 | 0.98655 |
| 52860 | 9 | 0.002617994 | 127 | 24 | 0 | 152.3 |
| 52860 |  | 0 | 127 | 15 | 0 | 12.7 |
| 52860 | -9 | -0.002617994 | 127 | 6 | 0 | -127.8 |
| 52860 |  | 0 | 127 | 15 | 0 | 13.1 | 0.98744 |
| 52860 | 10 | 0.002908882 | 127 | 25 | 0 | 169.9 |
| 52860 |  | 0 | 127 | 15 | 0 | 13.4 |
| 52860 | -10 | -0.002908882 | 127 | 5 | 0 | -141.3 |
| 52860 |  | 0 | 127 | 15 | 0 | 13.6 |

经过对仪器的各项测量结果进行不确定度评定，最终得到各项校准结果如下：

表3 磁通门经纬仪校准结果（兰州Mingeo）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.020±0.012)′  *I*：(0.010±0.006)′ |
| 2 | 仪器偏移 | *D*：(-0.030±0.021)′  *I*：(-0.060±0.018)′ |
| 3 | 磁通门经纬仪修正系数 | 0.9870±0.0020 |
| 4 | 线性度 | 0.37%±0.08% |
| 5 | 水平夹角 | (-0.60±0.02)′ |
| 6 | 垂直夹角 | (-0.76±0.02)′ |
| 7 | 零点偏移 | (8.58±0.18)nT |

2.2 蒙城、太原、乌鲁木齐、重庆仙女山、红山校准结果

表4.1 磁通门经纬仪校准结果（蒙城Mag01）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.020±0.012)′  *I*：(0.020±0.012)′ |
| 2 | 仪器偏移 | *D*：(-0.050±0.020)′  *I*：(-0.090±0.017)′ |
| 3 | 磁通门经纬仪修正系数 | 0.9995±0.0021 |
| 4 | 线性度 | 0.35%±0.08% |
| 5 | 水平夹角 | (1.71±0.00)′ |
| 6 | 垂直夹角 | (1.93±0.10)′ |
| 7 | 零点偏移 | (3.00±0.39)nT |

表4.2 磁通门经纬仪校准结果（太原Mingeo）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.060±0.038)′  *I*：(0.050±0.019)′ |
| 2 | 仪器偏移 | *D*：(0.280±0.041)′  *I*：(0.050±0.012)′ |
| 3 | 磁通门经纬仪修正系数 | 1.0039±0.0167 |
| 4 | 线性度 | 0.37%±0.08% |
| 5 | 水平夹角 | (0.63±0.01)′ |
| 6 | 垂直夹角 | (1.90±0.01)′ |
| 7 | 零点偏移 | (0.63±0.15)nT |

表4.3 磁通门经纬仪校准结果（乌鲁木齐Mingeo）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.010±0.006)′  *I*：(0.010±0.006)′ |
| 2 | 仪器偏移 | *D*：(0.010±0.023)′  *I*：(0.020±0.020)′ |
| 3 | 磁通门经纬仪修正系数 | 0.9961±0.0004 |
| 4 | 线性度 | 0.08%±0.02% |
| 5 | 水平夹角 | (-1.12±0.00)′ |
| 6 | 垂直夹角 | (-2.17±0.02)′ |
| 7 | 零点偏移 | (-0.08±0.03)nT |

表4.4 磁通门经纬仪校准结果（重庆仙女山Mag01）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.029±0.044)′  *I*：(0.010±0.012)′ |
| 2 | 仪器偏移 | *D*：(0.120±0.065)′  *I*：(-0.080±0.013)′ |
| 3 | 磁通门经纬仪修正系数 | 1.0142±0.0166 |
| 4 | 线性度 | 0.35%±0.10% |
| 5 | 水平夹角 | (-3.78±0.03)′ |
| 6 | 垂直夹角 | (1.78±0.02)′ |
| 7 | 零点偏移 | (6.63±0.53)nT |

表4.5 磁通门经纬仪校准结果（红山J2）

|  |  |  |
| --- | --- | --- |
| 序号 | 校准项目 | 校准结果 |
| 1 | 测量精密度 | *D*：(0.020±0.013)′  *I*：(0.010±0.009)′ |
| 2 | 仪器偏移 | *D*：(0.060±0.015)′  *I*：(0.050±0.009)′ |
| 3 | 磁通门经纬仪修正系数 | -0.9960±0.0021 |
| 4 | 线性度 | 0.44%±0.05% |
| 5 | 水平夹角 | (-0.01±0.02)′ |
| 6 | 垂直夹角 | (0.03±0.02)′ |
| 7 | 零点偏移 | (0.15±0.10)nT |