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**版次变更记录Revision Summary**

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1. 项目概述及计算输入

山西南桦山风电场位于朔州西部属温带大陆性季风气候，西风为主。本次测风塔位于山西南桦山风电场所示机位西北侧约120m处，海拔1803米。激光雷达位置示意图见图1-1。测风周期为：2020.09.16 14:00:00 至 2021.01.19 01:00:00。



图 1-1测风塔位置示意图

我部安装的测风塔工作环境和技术指标如下表：

表 1-1主要参数的合理范围参考值

|  |  |  |
| --- | --- | --- |
| **序号** | **环境** | **参数** |
| 1 | 工作温度，℃ | -35°C to +45°C |
| 2 | 存储温度，℃ | -45°C to +50°C |
| 3 | 工作相对湿度，% | 0% to 100% RH |
| 4 | 工作海拔，m | ≦3500 |
| 5 | 防尘防水等级 | 内部组件IP67 |
| 6 | 电源要求,V | 24V DC/220V AC |
| 7 | 抗震动 | ISTA/FEDEX 6A |
| 8 | 安全性 | Class 1M IEC / EN 60825-1 |
| 9 | 认证 | 欧盟CE认证 |
| 10 | 测量范围 | 40米到400米 |
| 11 | 测量高层数量 | 12层 |
| 12 | 测量高层最小间隔 | 1米 |
| 13 | 风速测量范围 | 0到80m/s |
| 14 | 风速测量精度 | 0.1 m/s |
| 15 | 风向测量范围 | 0到359° |
| 16 | 风向测量精度： | ≤1° |

1. 测风数据验证和处理
   1. 数据合理性检验

根据《风电场风能资源评估方法》（GB/T18710-2002），对测风塔参考周期的测风数据进行合理范围检验、相关性检验以及变化趋势检验。

a）范围检验

主要参数的合理范围参考值为：平均风速，0≤小时平均值＜40m/s；风向，0º≤小时平均值＜360º；94kPa≤水汽压（海平面）＜106 kPa。

表 2-1测风塔主要参数的合理范围参考值

| **主要参数** | **合理范围** |
| --- | --- |
| 平均风速 | 0≤小时平均值＜40m/s |
| 风向 | 0º≤小时平均值＜360º |
| 平均气压（海平面） | 94kPa≤小时平均值＜106 kPa |

表 2-2测风塔各层风速合理性检验表

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **编号** | **高度** | **检验标准** | **不合理数** | **发生时间** |
| 1488# | 1 | 0≤小时平均数＜40m/s | 1 | 1 |
| 1489# | 1 | 0≤小时平均数＜40m/s | 1 | 1 |
| 1 | 1 | 1 |

|  |  |  |  |
| --- | --- | --- | --- |
| **高度** | **检验标准** | **不合理数** | **发生时间** |
| 50m | 0≤小时平均数＜40m/s | 0 | - |
| 65m | 0 | - |
| 70m | 0 | - |
| 80m | 0 | - |
| 90m | 0 | - |
| 100m | 0 | - |
| 120m | 0 | - |
| 140m | 0 | - |
| 170m | 0 | - |
| 200m | 0 | - |
| 250m | 0 | - |
| 290m | 0 | - |

表 2-3测风塔各层风向合理性检验表

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **编号** | **高度** | **检验标准** | **不合理数** | **发生时间** |
| 1488# | 2 | 0º≤小时平均值＜360º | 2 | 2 |
| 1489# | 2 | 0º≤小时平均值＜360º | 2 | 2 |
| 2 | 2 | 2 |

|  |  |  |  |
| --- | --- | --- | --- |
| **高度** | **检验标准** | **不合理数** | **发生时间** |
| 50m | 0º≤小时平均值＜360º | 0 | - |
| 65m | 0 | - |
| 70m | 0 | - |
| 80m | 0 | - |
| 90m | 0 | - |
| 100m | 0 | - |
| 120m | 0 | - |
| 140m | 0 | - |
| 170m | 0 | - |
| 200m | 0 | - |
| 250m | 0 | - |
| 290m | 0 | - |

表2-4测风塔各层气压合理性检验

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **编号** | **高度** | **检验标准** | **不合理数** | **发生时间** |
| 1488# | 3 | 94kPa≤小时平均值＜106 kPa（海平面） | 3 | 3 |
| 1489# | 3 | 94kPa≤小时平均值＜106 kPa（海平面） | 3 | 3 |
| 3 | 3 | 3 |

|  |  |  |  |
| --- | --- | --- | --- |
| **高度** | **检验标准** | **不合理数** | **发生时间** |
| 50m | 94kPa≤小时平均值＜106 kPa（海平面） | 0 | - |
| 65m | 0 | - |
| 70m | 0 | - |
| 80m | 0 | - |
| 90m | 0 | - |
| 100m | 0 | - |
| 120m | 0 | - |
| 140m | 0 | - |
| 170m | 0 | - |
| 200m | 0 | - |
| 250m | 0 | - |
| 290m | 0 | - |

通过数据统计，激光雷达的各层数值，均在合理的范围内。

b）相关性检验

由于激光雷达的风速测层有290m、250m、200m、170m、140m、120m、100m、90m、80m、70m、65m、50m，风向测层有290m、250m、200m、170m、140m、120m、100m、90m、80m、70m、65m、50m。

根据实际情况，调整相关性检验的测层与参数，主要参数的合理相关性参考表2-5所示。

表 2-5测风塔各层相关性参考表

|  |  |  |
| --- | --- | --- |
| **编号** | **主要参数** | **合理相关性** |
| 1488# | 4 | 4 |
| 4 | 4 |
| 4.0 | 4.0 |
| 4.0 | 4.0 |
| 4.0 | 4.0 |
| 4.0 | 4.0 |
| 1489# | 4 | 4 |
| 4 | 4 |
| 4.0 | 4.0 |
| 4.0 | 4.0 |

| **主要参数** | **合理相关性** |
| --- | --- |
| 290m/250m测层小时平均风速差值 | ＜4.0m/s |
| 250m/200m测层小时平均风速差值 | ＜5.0m/s |
| 200m/170m测层小时平均风速差值 | ＜3.0m/s |
| 170m/140m测层小时平均风速差值 | ＜3.0m/s |
| 140m/120m测层小时平均风速差值 | ＜2.0m/s |
| 120m/100m测层小时平均风速差值 | ＜2.0m/s |
| 100m/90m测层小时平均风速差值 | ＜1.0m/s |
| 90m/80m测层小时平均风速差值 | ＜1.0m/s |
| 80m/70m测层小时平均风速差值 | ＜1.0m/s |
| 70m/65m测层小时平均风速差值 | ＜0.5m/s |
| 65m/50m测层小时平均风速差值 | ＜1.5m/s |
| 290m/250m测层风向差值 | ＜22.5° |
| 250m/200m测层风向差值 | ＜22.5° |
| 200m/170m测层风向差值 | ＜22.5° |
| 170m/140m测层风向差值 | ＜22.5° |
| 140m/120m测层风向差值 | ＜22.5° |
| 120m/100m测层风向差值 | ＜22.5° |
| 100m/90m测层风向差值 | ＜22.5° |
| 90m/80m测层风向差值 | ＜22.5° |
| 80m/70m测层风向差值 | ＜22.5° |
| 70m/65m测层风向差值 | ＜22.5° |
| 65m/50m测层风向差值 | ＜22.5° |

表 2-6 测风塔各层风速相关性性检验

|  |  |  |  |
| --- | --- | --- | --- |
| **编号** | **高度** | **不合理数** | **发生时间** |
| 1488# | 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |
| 1489# | 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |
| 5 | 5 | 5 |

|  |  |  |
| --- | --- | --- |
| **高度** | **不合理数** | **发生时间** |
| 290m-250m | 131 | 2020/10/2-5、2020/11/23、2020/12/16-21 |
| 250m-200m | 94 | 2020/10/16-17、2020/11/23、2020/12/16-18 |
| 200m-170m | 35 | 2020/09/29、2020/11/17、2020/12/05、2020/12/17 |
| 170m-140m | 17 | 2020/10/30、2020/11/17、2020/11/18、2020/11/20、2020/11/23 |
| 140m-120m | 16 | 2020/11/18 08:00:00- 2020/11/19 02:00:00,、2020/11/28、2020/12/05 |
| 120m-100m | 10 | 2020/11/18 09:00:00- 2020/11/19 03:00:00 |
| 100m-90m | 5 | 2020/11/19 04:00:00- 06:00:00 |
| 90m-80m | 15 | 2020/10/07、2020/10/09、2020/11/16,、2020/11/18 |
| 80m-70m | 30 | 2020/11/15 18:00:00 -2020/11/18 23:00:00 |
| 70m-65m | 1 | 2020/11/18 22:00:00 |
| 65m-50m | 1 | 2020/11/18 10:00:00 |

表 2-7测风塔各层风向相关性性检验

|  |  |  |  |
| --- | --- | --- | --- |
| **编号** | **高度** | **不合理数** | **发生时间** |
| 1488# | 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |
| 1489# | 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |
| 6 | 6 | 6 |

|  |  |  |
| --- | --- | --- |
| **高度** | **不合理数** | **发生时间** |
| 290m-250m | 213 | 22020/10/2-5、2020/11/16-24、2020/12/16-20、2020/12/31 |
| 250m-200m | 208 | 2020/09/29-30、2020/10/2-5、2020/11/16-24、2020/12/16-18 |
| 200m-170m | 67 | 2020/09/29、2020/10/05、2020/11/17-24、2020/12/16-17 |
| 170m-140m | 64 | 2020/10/23、2020/11/17-20、2020/11/23、2020/11/28 |
| 140m-120m | 34 | 2020/10/23、2020/11/18-20,、2020/11/23、2020/11/28 |
| 120m-100m | 27 | 2020/10/23、2020/11/18-20,、2020/11/23、2020/11/25 |
| 100m-90m | 10 | 2020/11/18,、2020/11/19 |
| 90m-80m | 14 | 2020/10/09、2020/11/18,、2020/11/21、2020/11/25 |
| 80m-70m | 13 | 2020/11/18,、2020/11/20、2020/11/23 |
| 70m-65m | 6 | 2020/10/28、2020/11/18,、2020/11/20、2020/11/23 |
| 65m-50m | 2 | 2020/11/18 10:00:00 |

c）趋势检验

趋势检验判断标准：

表 2-8 主要参数的合理范围参考值

| **主要参数** | **合理范围** |
| --- | --- |
| 1h平均风速变化 | ＜6m/s |
| 1h平均温度变化 | ＜5º |
| 3h平均气压变化 | ＜1 kPa |

表 2-9 测风塔各层风速趋势检验

|  |  |  |  |
| --- | --- | --- | --- |
| **编号** | **高度** | **不合理数** | **发生时间** |
| 1488# | 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |
| 1489# | 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |
| 7 | 7 | 7 |

|  |  |  |
| --- | --- | --- |
| **高度** | **不合理数** | **发生时间** |
| 250m | 54 | 2020/10/2-5、2020/11/18-19、2020/12/14-18 |
| 200m | 32 | 2020/10/02、2020/11/18-19、2020/12/16-18 |
| 170m | 15 | 2020/09/29、2020/11/17、2020/12/05、2020/12/17 |
| 140m | 10 | 2020/10/10、2020/11/18-19、2020/12/05、2020/12/06 |
| 120m | 8 | 2020/10/10-11、2020/11/18-19、2020/12/05、2020/12/06 |
| 100m | 6 | 2020/11/18-19、2020/12/05、2020/12/06 |
| 90m | 3 | 2020/11/18、2020/12/05、2020/12/06 |
| 80m | 2 | 2020/11/18、2020/12/25 |
| 70m | 2 | 2020/11/18、2020/11/23 |
| 65m | 1 | 2020/11/18 |
| 50m | 1 | 2020/11/18 |

表 2-10 测风塔气温趋势检验

|  |  |  |  |
| --- | --- | --- | --- |
| **编号** | **高度** | **不合理数** | **发生时间** |
| 1488# | 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |
| 1489# | 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |
| 8 | 8 | 8 |

经统计，1h平均温度变化超过5º共23个，主要发生在：2020/10/02-04、2020/10/09-11、2020/11/02-03、2020/11/18、2020/11/23。

表 2-11 测风塔气压趋势检验

|  |  |  |  |
| --- | --- | --- | --- |
| **编号** | **高度** | **不合理数** | **发生时间** |
| 1488# | 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |
| 1489# | 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |
| 9 | 9 | 9 |

3h内的气压变化趋势较为合理，没有不合理数值。

因此经通过范围检验，相关性检验以及趋势检验，认为200m以下的数据是符合实际情况的有效数据，可以回归原始数组。200m以上数据酌情回归原始数组。

* 1. 完整性检验

式中：

应测数目— 测量期间小时数；

缺测数目— 没有记录到的小时平均值数目；

无效数据数目— 确认为不合理的小时平均值数目；

激光雷达在所收集测风期内的数据完整率如表2-10所示。激光雷达各测层间相关关系如表2-11所示。

表 2-12 测风塔各层完整率表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **编号** | **时间段** | | **测层** | **应测数据** | **实测数据** | **完整率（%）** |
| 1488# | | 10 | 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 1489# | | 10 | 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |
| 10 | 10 | 10 | 10 |

| **测风塔** | **时间段** | **测层** | **应测数据** | **实测数据个数** | **完整率（%）** |
| --- | --- | --- | --- | --- | --- |
| 激光雷达 | 2020.9.25~2020.12.25 | 50m | 2,185 | 2,178 | 99.68 |
| 65m | 2,185 | 2,179 | 99.73 |
| 70m | 2,185 | 2,176 | 99.59 |
| 80m | 2,185 | 2,170 | 99.31 |
| 90m | 2,185 | 2,167 | 99.18 |
| 100m | 2,185 | 2,157 | 98.72 |
| 120m | 2,185 | 2,148 | 98.31 |
| 140m | 2,185 | 2,133 | 97.62 |
| 170m | 2,185 | 2,102 | 96.2 |
| 200m | 2,185 | 2,078 | 95.1 |
| 250m | 2,185 | 1,948 | 89.15 |
| 290m | 2,185 | 1,799 | 82 |
| 50mD | 2,185 | 2,178 | 99.68 |
| 65mD | 2,185 | 2,179 | 99.73 |
| 70mD | 2,185 | 2,176 | 99.59 |
| 80mD | 2,185 | 2,170 | 99.31 |
| 90mD | 2,185 | 2,167 | 99.18 |
| 100mD | 2,185 | 2,157 | 98.72 |
| 120mD | 2,185 | 2,148 | 98.31 |
| 140mD | 2,185 | 2,133 | 97.62 |
| 170mD | 2,185 | 2,102 | 96.2 |
| 200mD | 2,185 | 2,078 | 95.1 |
| 250mD | 2,185 | 1,948 | 89.15 |
| 290mD | 2,185 | 1,799 | 82 |
| 8m-Temp | 2,185 | 2979 | 99.799 |
| 8m-kPa | 2,185 | 2979 | 99.799 |

表2-13测风塔各层相关性统计表（R2）

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 测层 | 290m | 250m | 200m |
| 1488# | 290m | -- | 0.993 | 0.961 |
| 250m | -- | -- | 0.985 |
|  | 测层 | 290m | 250m | 200m |
| 1489# | 290m | -- | 0.993 | 0.961 |
| 250m | -- | -- | 0.985 |
| 200m | -- | -- | 0.985 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 测层 | 290m | 250m | 200m | 170m | 140m | 120m | 100m | 90m | 80m | 70m | 65m | 50m |
| 290m |  | 0.993 | 0.961 | 0.932 | 0.893 | 0.860 | 0.821 | 0.802 | 0.785 | 0.766 | 0.754 | 0.718 |
| 250m |  |  | 0.985 | 0.962 | 0.927 | 0.895 | 0.856 | 0.837 | 0.818 | 0.796 | 0.783 | 0.744 |
| 200m |  |  |  | 0.993 | 0.970 | 0.944 | 0.910 | 0.891 | 0.870 | 0.845 | 0.829 | 0.788 |
| 170m |  |  |  |  | 0.991 | 0.973 | 0.945 | 0.928 | 0.908 | 0.882 | 0.867 | 0.825 |
| 140m |  |  |  |  |  | 0.995 | 0.978 | 0.966 | 0.949 | 0.925 | 0.910 | 0.872 |
| 120m |  |  |  |  |  |  | 0.994 | 0.986 | 0.973 | 0.953 | 0.939 | 0.904 |
| 100m |  |  |  |  |  |  |  | 0.998 | 0.991 | 0.975 | 0.964 | 0.935 |
| 90m |  |  |  |  |  |  |  |  | 0.997 | 0.985 | 0.976 | 0.951 |
| 80m |  |  |  |  |  |  |  |  |  | 0.995 | 0.990 | 0.971 |
| 70m |  |  |  |  |  |  |  |  |  |  | 0.999 | 0.989 |
| 65m |  |  |  |  |  |  |  |  |  |  |  | 0.994 |
| 50m |  |  |  |  |  |  |  |  |  |  |  |  |

激光雷达各测层间相关关系较好，相邻两测层间相关性超过98%。有缺失数据建议用相关性较好的相邻测层进行插补。

1. 空气密度

测风塔安装有温度、气压测量仪器资料，可根据下式计算得到风电场空气密度：

式中：

为空气密度（kg/m³）；

为年平均气压（Pa）；

为气体常数（287J/kg.K）；

为年平均开氏温标绝对温度（）。

根据测风雷达数据，平均气温0.988℃，年平均气压82.17kPa，测风塔2m高度处空气密度为1.049kg/m³。

1. 平均风速

对整理后的测风塔进行统计，得到各测风高度的平均风速如下所示：

表2-14测风塔各层平均风速表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 高度 | 50m | 65m | 70m | 80m | 90m |
| 1488# | 现场空气密度平均风速（m/s） | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 |
| 标况下平均风速（m/s） | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
|  | 高度 | 50m | 65m | 70m | 80m | 81m |
| 1489# | 现场空气密度平均风速（m/s） | 4.423 | 4.544 | 4.596 | 4.704 | 4.544 |
| 标况下平均风速（m/s） | 4.352 | 4.478 | 4.55 | 4.696 | 4.478 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 高度（m) | 50m | 65m | 70m | 80m | 90m | 100m | 120m | 140m | 170m | 200m | 250m | 290m |
| 现场空气密度平均风速（m/s） | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 | 4.916 | 5.109 | 5.294 | 5.556 | 5.790 | 6.082 | 6.378 |
| 标况下平均风速（m/s） | 4.352 | 4.478 | 4.550 | 4.696 | 4.836 | 4.932 | 5.144 | 5.347 | 5.668 | 5.927 | 6.443 | 6.861 |

表2-15测风塔各层逐时平均风速表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 高度 | 50m | 65m | 70m | 80m | 90m |
| 1488# | 01:00:00 | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 |
| 02:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 03:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 04:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 05:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 06:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 07:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 08:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 09:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 10:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 11:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 12:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 13:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 14:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 15:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 16:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 17:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 18:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 19:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 20:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 21:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 22:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 23:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
|  | 高度 | 50m | 65m | 70m | 80m | 81m |
| 1489# | 01:00:00 | 4.423 | 4.544 | 4.596 | 4.704 | 4.544 |
| 02:00:00 | 4.352 | 4.478 | 4.55 | 4.696 | 4.478 |
| 03:00:00 | 4.281 | 4.412 | 4.504 | 4.688 | 4.412 |
| 04:00:00 | 4.21 | 4.346 | 4.458 | 4.68 | 4.346 |
| 05:00:00 | 4.139 | 4.28 | 4.412 | 4.672 | 4.28 |
| 06:00:00 | 4.068 | 4.214 | 4.366 | 4.664 | 4.214 |
| 07:00:00 | 3.997 | 4.148 | 4.32 | 4.656 | 4.148 |
| 08:00:00 | 3.926 | 4.082 | 4.274 | 4.648 | 4.082 |
| 09:00:00 | 3.855 | 4.016 | 4.228 | 4.64 | 4.016 |
| 10:00:00 | 3.784 | 3.95 | 4.182 | 4.632 | 3.95 |
| 11:00:00 | 3.713 | 3.884 | 4.136 | 4.624 | 3.884 |
| 12:00:00 | 3.642 | 3.818 | 4.09 | 4.616 | 3.818 |
| 13:00:00 | 3.571 | 3.752 | 4.044 | 4.608 | 3.752 |
| 14:00:00 | 3.5 | 3.686 | 3.998 | 4.6 | 3.686 |
| 15:00:00 | 3.429 | 3.62 | 3.952 | 4.592 | 3.62 |
| 16:00:00 | 3.358 | 3.554 | 3.906 | 4.584 | 3.554 |
| 17:00:00 | 3.287 | 3.488 | 3.86 | 4.576 | 3.488 |
| 18:00:00 | 3.216 | 3.422 | 3.814 | 4.568 | 3.422 |
| 19:00:00 | 3.145 | 3.356 | 3.768 | 4.56 | 3.356 |
| 20:00:00 | 3.074 | 3.29 | 3.722 | 4.552 | 3.29 |
| 21:00:00 | 3.003 | 3.224 | 3.676 | 4.544 | 3.224 |
| 22:00:00 | 2.932 | 3.158 | 3.63 | 4.536 | 3.158 |
| 23:00:00 | 2.861 | 3.092 | 3.584 | 4.528 | 3.092 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 高度（m) | 50m | 65m | 70m | 80m | 90m | 100m | 120m | 140m | 170m | 200m | 250m | 290m |
| 0 |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 | 4.916 | 5.109 | 5.294 | 5.556 | 5.790 | 6.082 | 6.378 |
| 8 |  |  |  |  |  |  |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 |  |  |  |  |  |  |  |  |  |  |  |  |
| 13 |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 |  |  |  |  |  |  |  |  |  |  |  |  |
| 16 |  |  |  |  |  |  |  |  |  |  |  |  |
| 17 |  |  |  |  |  |  |  |  |  |  |  |  |
| 18 |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 |  |  |  |  |  |  |  |  |  |  |  |  |
| 20 |  |  |  |  |  |  |  |  |  |  |  |  |
| 21 |  |  |  |  |  |  |  |  |  |  |  |  |
| 22 |  |  |  |  |  |  |  |  |  |  |  |  |
| 23 |  |  |  |  |  |  |  |  |  |  |  |  |
| 平均风速（m/s) | 4.500 | 4.633 | 4.697 | 4.830 | 4.962 | 5.074 | 5.307 | 5.538 | 5.885 | 6.185 | 6.647 | 7.025 |

表2-16测风塔各层逐月平均风速表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 高度 | 50m | 65m | 70m | 80m | 90m |
| 1488# | 1 月 | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 |
| 2 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 3 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 4 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 5 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 6 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 7 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 8 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 9 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 10 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 11 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 12 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
|  | 高度 | 50m | 65m | 70m | 80m | 81m |
| 1489# | 1 月 | 4.423 | 4.544 | 4.596 | 4.704 | 4.544 |
| 2 月 | 4.352 | 4.478 | 4.55 | 4.696 | 4.478 |
| 3 月 | 4.281 | 4.412 | 4.504 | 4.688 | 4.412 |
| 4 月 | 4.21 | 4.346 | 4.458 | 4.68 | 4.346 |
| 5 月 | 4.139 | 4.28 | 4.412 | 4.672 | 4.28 |
| 6 月 | 4.068 | 4.214 | 4.366 | 4.664 | 4.214 |
| 7 月 | 3.997 | 4.148 | 4.32 | 4.656 | 4.148 |
| 8 月 | 3.926 | 4.082 | 4.274 | 4.648 | 4.082 |
| 9 月 | 3.855 | 4.016 | 4.228 | 4.64 | 4.016 |
| 10 月 | 3.784 | 3.95 | 4.182 | 4.632 | 3.95 |
| 11 月 | 3.713 | 3.884 | 4.136 | 4.624 | 3.884 |
| 12 月 | 3.642 | 3.818 | 4.09 | 4.616 | 3.818 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 高度（m) | 50m | 65m | 70m | 80m | 90m | 100m | 120m | 140m | 170m | 200m | 250m | 290m |
| 10 月（m/s） | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 | 4.916 | 5.109 | 5.294 | 5.556 | 5.790 | 6.082 | 6.378 |
| 11 月（m/s） | 4.352 | 4.478 | 4.550 | 4.696 | 4.836 | 4.932 | 5.144 | 5.347 | 5.668 | 5.927 | 6.443 | 6.861 |
| 12 月（m/s） | 5.141 | 5.306 | 5.378 | 5.529 | 5.681 | 5.840 | 6.193 | 6.555 | 7.102 | 7.596 | 8.351 | 8.844 |
| 平均风速（m/s) | 4.500 | 4.633 | 4.697 | 4.830 | 4.962 | 5.074 | 5.307 | 5.538 | 5.885 | 6.185 | 6.647 | 7.025 |

1. 风切变

风切变在这里指的是风的垂直切变，是水平风速在垂直距离上的变化。风切变指数随着场址位置、测层不同而不同。风切变指数越大，证明轮毂高度越高，风资源条件越好，能获得更好的发电效益，但风切变过大，作用于风机叶轮的荷载则更不平衡，不利于风机的稳定运行。IEC 61400-1以0.2的风切变指数定义风机设计的垂直风况条件，由于风切变受地形、地貌、年份、季节等影响。在内陆平坦地形风电场，受地表粗糙度的影响，容易产生较大的风切变现象。风速随高度变化服从普朗特经验公式，利用风切变幂律（风廓线）公式求得不同高度的风切变指数。

文本

描述已自动生成

风切变指数越大，证明越往高处，风速的增长的指数关系越大。风切变指数越小，证明越往高处，风速的增长的指数关系越小。

1498#测风塔 100m处综合风切变指数0.272；

1499#测风塔 100m处综合风切变指数0.290；测风塔各测层间实测风切变指数见表2-9、表2-10。实测及拟合后的垂直风廓线见图2-7。

表2-17 测风塔各层风切变指数表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 测层 | 100mA | 100mB | 80mA | 80mB | 50m |
| 1488# | 100mA | -- | -- | 0.247 | 0.252 | 0.265 |
| 100mB | -- | -- | 0.285 | 0.289 | 0.277 |
| 80mA | -- | -- | -- | -- | 0.273 |
| 80mB | -- | -- | -- | -- | 0.271 |
|  | 测层 | 100mA | 100mB | 80mA | 80mB | 81mB |
| 1489# | 100mA | -- | -- | 0.247 | 0.252 | 0.265 |
| 100mB | -- | -- | 0.285 | 0.289 | 0.277 |
| 80mA | -- | -- | -- | -- | 0.273 |
| 80mB | -- | -- | -- | -- | 0.271 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 测层 | 100mA | 100mB | 80mA | 80mB | 50m | 30m |
| 100mA |  | -- | 0.247 | 0.252 | 0.265 | 0.266 |
| 100mB |  |  | 0.285 | 0.289 | 0.277 | 0.273 |
| 80mA |  |  |  | -- | 0.273 | 0.271 |
| 80mB |  |  |  |  | 0.271 | 0.270 |
| 50m |  |  |  |  |  | 0.268 |
| 30m |  |  |  |  |  |  |

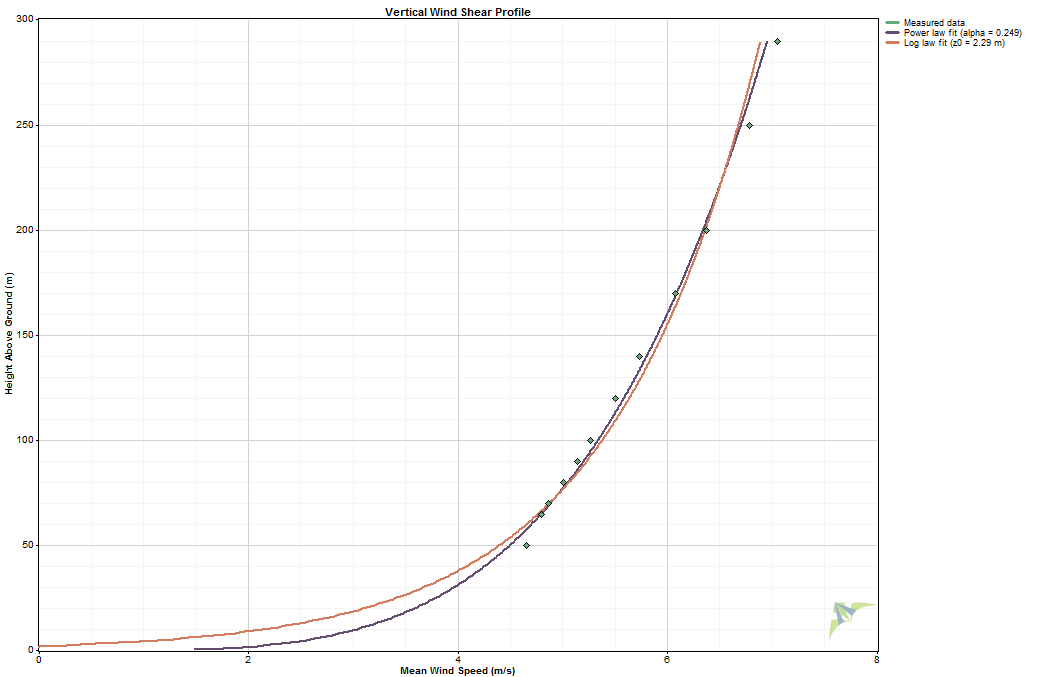


图 2-1 风切变图（50m-290m）

1. 湍流强度

湍流是指风速、风向及其垂直分量的迅速扰动或不规律性，是重要的风况特征和评价气流稳定程度的指标。其很大程度上取决于环境的粗糙度、地层稳定性和障碍物。湍流强度是脉动风速的均方差与平均风速的比值。其计算公式为：

|  |
| --- |
|  |

式中：I—湍流强度；

v—10min风速标准偏差，m/s；

—10min平均风速，m/s。

对1498#、1499# 测风塔完整年期间的数据进行湍流强度统计，IEC标准中规定湍流强度采用15m/s风速段进行湍流的计算。各测层的湍流强度如表2-11、表2-12。1498#、1499# 测风塔100m各风速段的湍流强度如图2-10、图2-11。测风雷达各测层湍流强度所示：

表2-18测风塔各层湍流强度表

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 高度 | 50m | 65m | 70m | 80m | 90m |
| 1488# | 1 | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 |
| 2 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 3 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 4 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 5 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 6 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 7 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 8 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 9 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 10 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 11 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 12 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 13 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 14 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 15 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 16 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 17 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 18 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 19 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
| 20 | 4.352 | 4.478 | 4.55 | 4.696 | 4.836 |
|  | 高度 | 50m | 65m | 70m | 80m | 81m |
| 1489# | 1 | 4.423 | 4.544 | 4.596 | 4.704 | 4.544 |
| 2 | 4.352 | 4.478 | 4.55 | 4.696 | 4.478 |
| 3 | 4.281 | 4.412 | 4.504 | 4.688 | 4.412 |
| 4 | 4.21 | 4.346 | 4.458 | 4.68 | 4.346 |
| 5 | 4.139 | 4.28 | 4.412 | 4.672 | 4.28 |
| 6 | 4.068 | 4.214 | 4.366 | 4.664 | 4.214 |
| 7 | 3.997 | 4.148 | 4.32 | 4.656 | 4.148 |
| 8 | 3.926 | 4.082 | 4.274 | 4.648 | 4.082 |
| 9 | 3.855 | 4.016 | 4.228 | 4.64 | 4.016 |
| 10 | 3.784 | 3.95 | 4.182 | 4.632 | 3.95 |
| 11 | 3.713 | 3.884 | 4.136 | 4.624 | 3.884 |
| 12 | 3.642 | 3.818 | 4.09 | 4.616 | 3.818 |
| 13 | 3.571 | 3.752 | 4.044 | 4.608 | 3.752 |
| 14 | 3.5 | 3.686 | 3.998 | 4.6 | 3.686 |
| 15 | 3.429 | 3.62 | 3.952 | 4.592 | 3.62 |
| 16 | 3.358 | 3.554 | 3.906 | 4.584 | 3.554 |
| 17 | 3.287 | 3.488 | 3.86 | 4.576 | 3.488 |
| 18 | 3.216 | 3.422 | 3.814 | 4.568 | 3.422 |
| 19 | 3.145 | 3.356 | 3.768 | 4.56 | 3.356 |
| 20 | 3.074 | 3.29 | 3.722 | 4.552 | 3.29 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 风速段 | 50m | 65m | 70m | 80m | 90m | 100m | 120m | 140m | 170m | 200m | 250m | 290m |
| 0 |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 4.423 | 4.544 | 4.596 | 4.704 | 4.816 | 4.916 | 5.109 | 5.294 | 5.556 | 5.790 | 6.082 | 6.378 |
| 8 |  |  |  |  |  |  |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 |  |  |  |  |  |  |  |  |  |  |  |  |
| 13 |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 |  |  |  |  |  |  |  |  |  |  |  |  |
| 16 |  |  |  |  |  |  |  |  |  |  |  |  |
| 17 |  |  |  |  |  |  |  |  |  |  |  |  |
| 18 |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 |  |  |  |  |  |  |  |  |  |  |  |  |
| 20 |  |  |  |  |  |  |  |  |  |  |  |  |

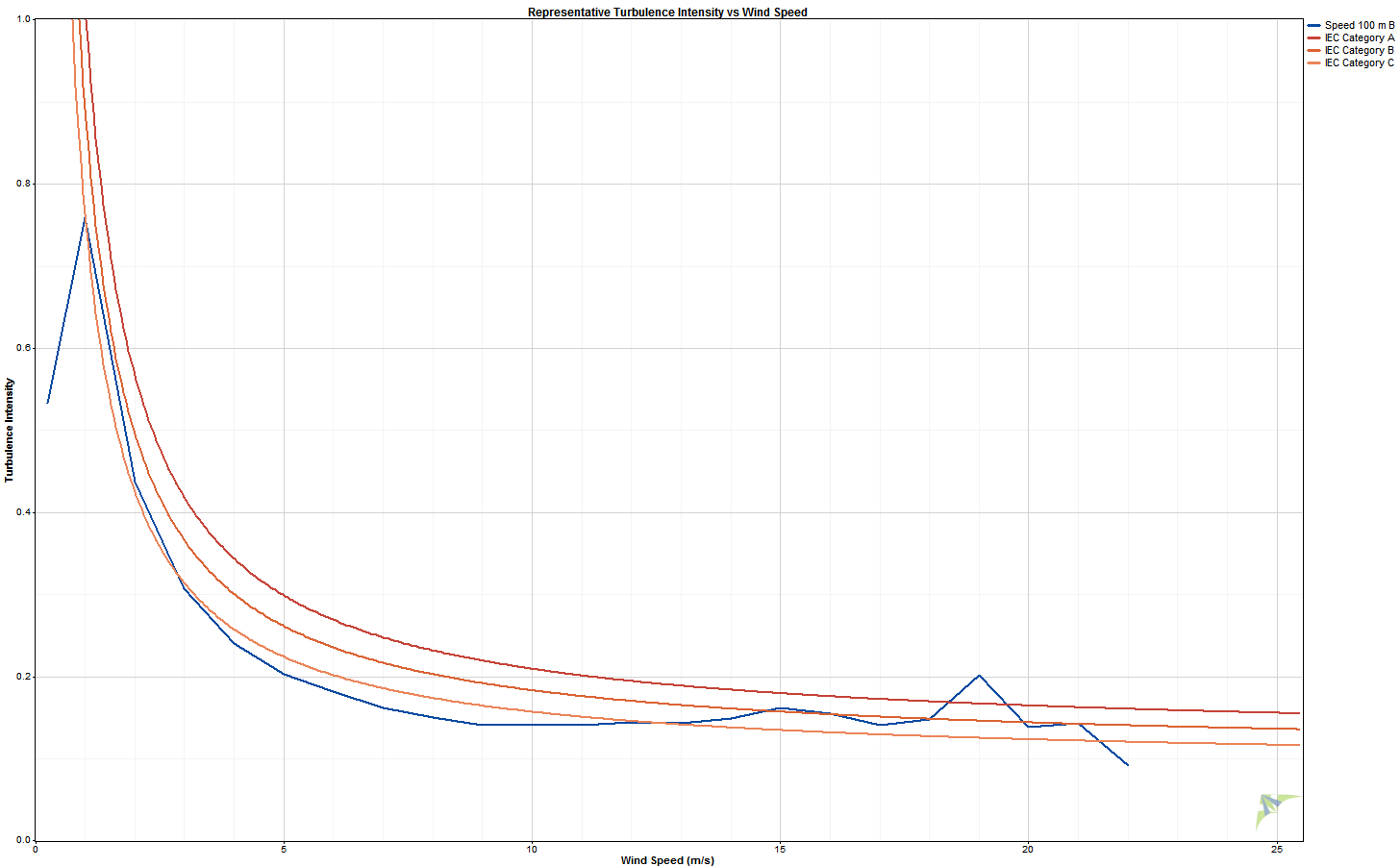


图2-11 1499#测风塔100m湍流强度（IEC3 版）

1. 风向及威布尔分布

按照《风电场风能资源评估方法》 GB/T 18710-2002 规范完成 1498#、1499#两座测风塔测风数据的处理与分析工作，参考周期内1498#测风塔100m高度的年平均风速为7.048m/s(折算到标准空气密度下为7.028m/s)，参考周期内1499#测风塔100m高度的年平均风速为6.927m/s，折算到标准空气密度下为6.907m/s)。参考周期内1498#测风塔A=7.90m/s，K=2.68，参考周期内1499#测风塔A=7.79m/s，K=2.45。不同风速区间占比统计如表2-8 所示。1498#测风塔 100m高度代表年威布尔分布参数如图2-5 所示，1499#测风塔 100m高度代表年威布尔分布参数如图2-6 所示。各高度的测风数据作为计算输入，风向如下图所示：

|  |  |
| --- | --- |
|  |  |
| **图 4-3风向玫瑰图和威布尔分布(K=2.049, C=5.079 50m)** | |
|  |  |
| **图 5-4风向玫瑰图和威布尔分布(K=2.089, C=5.229 65m)** | |
|  |  |
| **图 14-13风向玫瑰图和威布尔分布（K=1.982, C=7.510 290m)** | |

1. 总结

激光雷达从2020.09.16 14:00:00 至 2021.01.19 01:00:00，连续测风4.1个月，测层包含290m、250m、200m、170m、140m、120m、100m、90m、80m、70m、65m、50m的风速风向数据，选取2020.09.20 至2020.12.20 进行分析，数据测风质量较好，测层间的相关性高。参考周期内1498#测风塔100m高度的年平均风速为7.048m/s(折算到标准空气密度下为7.028m/s)，参考周期内1499#测风塔100m高度的年平均风速为6.927m/s，折算到标准空气密度下为6.907m/s)。