船舶与重防腐行业篇--德国菲尼克斯 PHYNIX 涂层测厚仪

在高端制造与工业防腐领域的应用指南

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上一篇《**汽车行业篇**》，我们聚焦于高速流水线、多层涂装、钢铝混线生产场景下，涂层测厚仪如何以“快速、精准、自动适配”满足批 量生产节奏。这一篇，我们将视角从陆地转向海洋，进入工业防腐领域**要求最严苛、工况最极端**的场景——船舶与重防腐。

如果说汽车行业的测量挑战在于**“快”和“薄”**，那么船舶与重防腐行业的核心命题则是 ****“粗”和“厚”**** ——基材表面极度粗糙（喷砂 Sa 2.5 级），涂层总厚度可达数百乃至上千微米，测量值的离散性极大，对仪器的**统计学评估能力**和**厚膜段线性度**提出了完全不同的技术要求。而 PHYNIX 的应对之道，也从“一键快速测量”切换为“多点统计分析与粗糙面校准”——同一套仪器平台，不同的应用策略，这正是 PHYNIX 跨行业通用性的最佳体现。

一、行业背景与涂层测量痛点

船舶制造与重防腐行业是涂层测厚仪应用的****发源地之一****，也是技术要求最高、标准最严格的领域。船舶在海洋环境中服役，面临****高盐雾、高湿度、强紫外线、海水冲击、阴极保护电位****等多重腐蚀因素的共同作用。一道涂层厚度不足的压载舱环氧涂层，可能导致一艘设计寿命 30 年的远洋巨轮在 15 年内即发生严重腐蚀，进坞维修费用高达数百万美元。

重防腐行业（包括海洋工程、桥梁钢结构、大型储罐等）同样面临着类似的严苛要求。这些设施的设计寿命通常长达 30-50 年, 涂层体系的防腐性能直接关系到结构安全与全生命周期成本。

船舶与重防腐行业面临的核心挑战：

- **极端粗糙表面**：喷砂/喷丸处理至 Sa 2.5 级，锚纹深度 Rz 达 50-100μm，单点测量值离散性极大（±50μm 常见）

- **超厚涂层体系**：典型船体外板涂层总厚度达 320μm 以上（富锌底漆 80μm+环氧云铁中间漆 150μm+聚氨酯面漆 100μm），部分重防腐场景达 600-1000μm 甚至更高

- **大面积快速抽检**：一艘 VLCC（超大型油轮）的涂装面积可达数十万平方米，需高效、系统的抽样方案

- **严格国际标准**：必须符合 ISO 19840（船舶与防护涂层体系）、PSPC（压载舱涂层性能标准）、IMO（国际海事组织）规范等

- **复杂几何结构**：船体外板的曲面、焊缝、R 角、舾装件等多样化结构，对探头可达性提出挑战

- **户外恶劣环境**：船坞/船台现场测量，受温度、湿度、盐雾、风沙等环境因素影响

二、典型基材与涂层特征

2.1 船舶与重防腐常用基材类型

基材类型	典型牌号/规格	电磁特性	适用测量原理
船用结构钢	A 级、D 级、E 级、AH32-DH36	铁磁性	磁感应法
高强度钢	EH36、FH40	铁磁性	磁感应法
不锈钢复合板	304L/316L 复合板	弱磁性/非磁性	涡流法（优先）
铸铁件	舾装件、锚链	铁磁性	磁感应法

2.2 船舶涂层体系与厚度要求

涂层位置	涂层体系	典型厚度	主要标准

船体外板（压载舱）	环氧底漆+环氧云铁中间漆+聚氨酯面漆	≥320 µm	PSPC、IMO MSC.215(82)
船体外板（干舷）	环氧底漆+聚氨酯面漆	200-300 µm	ISO 12944
船底（水线以下）	环氧底漆+防污漆	300-400 µm	ISO 12944
海洋平台桩腿	环氧富锌底漆+环氧中间漆+聚氨酯面漆	400-800 µm	NORSOK M-501
桥梁钢结构	环氧富锌+环氧云铁+聚氨酯/氟碳面漆	250-500 µm	ISO 12944 C5-M
储罐内壁	环氧/酚醛/玻璃鳞片涂层	300-1000 µm	API 652 / ISO 12944
防火涂层（被动防火）	膨胀型/非膨胀型防火涂料	2-10 mm	ISO 22899 / UL 1709

三、核心测量难点分析

3.1 粗糙表面对测量的根本性影响

这是船舶与重防腐行业涂层测厚****最核心的技术难题****。

当测厚仪探头接触喷砂处理后的钢材表面时，磁通线的长度受表面微观峰谷结构的影响显著：

- 峰值效应：在喷砂表面的凸峰处，磁通线更短，仪器显示涂层厚度偏厚
- 谷值效应：在喷砂表面的凹谷处，磁通线更长，仪器显示涂层厚度偏薄
- 结果：单点测量值离散性极大，真实涂层厚度被系统性高估

平滑表面与粗糙表面磁通线长度的差异

在相同峰层厚度条件下，平滑表面与粗糙表面测量时的不同磁通线长度

PHYNIX 的应对策略：采用同材质、同粗糙度的未涂装裸板进行零点校准，并配合多点测量统计评估（详见第五章）。

3.2 超厚涂层的高线性度测量

船体外板涂层总厚度通常在 300-800μm 范围，部分重防腐场景可达 1000-2000μm。普通测厚仪在厚膜段容易出现线性度漂移，导致系统性偏差。PHYNIX Surfix® Pro X 支持**多点校准曲线**功能（使用 50/100/200/500μm 等多片标准片进行拟合），确保厚膜段线性度优于±2%。

3.3 ISO 19840 标准的统计评估要求

ISO 19840 标准规定了船舶与防护涂层体系干膜厚度的测量与验收方法, 核心要求包括:

- 测量区域（Spot）：每个区域至少测量 3 个点，取平均值作为该区域代表值
- 区域数量（Area）：每 $10m^2$至少测量 1 个区域（不同标准有差异）
- 验收标准: 所有区域平均值的平均值 ≥ 额定干膜厚度 (NDFT)；每个区域平均值 ≥ 0.8×NDFT；每个单点值 ≥ 0.8×NDFT（部分标准）
- 不得出现“低于规格”的点：任何单点读数不得低于 NDFT 的 0.8 倍

这意味着仪器必须具备**实时统计计算功能**（自动计算 n、Mean、SD、Max、Min），并能快速识别不合格点。

3.4 大面积测量的抽样效率

一艘 VLCC 的压载舱涂装面积可达 5,000-10,000m^2。按 ISO 19840 要求，每 $10m^2$取一个测量区域, 每个区域 3-5 个测量点——这意味着一次完整的压载舱验收需进行数千次有效测量。仪器的人机工学设计（单手操作、轻量化、数据存储与导出）直接影响现场检测效率。

3.5 高温与高湿环境下的测量稳定性

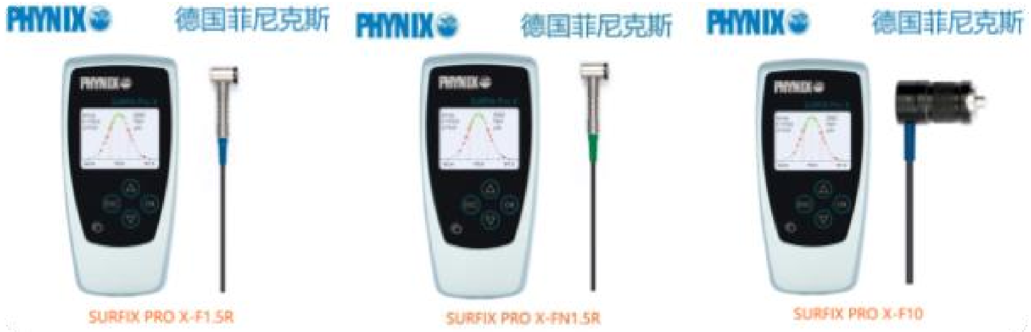
船坞现场环境复杂：夏季钢板表面温度可达 60°C 以上，冬季接近 0°C；空气湿度常超过 80%，存在盐雾腐蚀风险。PHYNIX 探头采用密封防潮设计，配合自动温度补偿功能，可在 0-60°C 环境温度范围内保持测量精度。测量前建议仪器与标准片在环境温度下稳

定至少 15 分钟。

四、PHYNIX 推荐产品组合

4.1 船体外板与重防腐涂层（标准场景）

推荐型号	探头配置	核心优势	适用场景
Surfix® Pro X	直探头 FN1.5（量程 0-1500µm）	多点校准曲线、统计功能、蓝牙数据传输、100,000 个数据存储	船体外板、压载舱、桥梁、储罐的标准厚度测量与验收
Surfix® Pro X	直探头 FN3.5（Fe:0-3500µm/NFe:0-3000µm）	扩展量程，适用于厚涂层体系	海洋平台桩腿（400-800µm）、重防腐厚涂层
Surfix® Pro X + F3.0/F10	厚涂层专用探头	量程达 10mm（扩展）	防火涂层（2-10mm）



4.2 粗糙表面专用测量

推荐型号	配置说明	核心优势
Surfix® Pro X + FN1.5（粗糙校准模式）	启用粗糙表面校准功能	同材质同粗糙度裸板零点校准，每组 5-10 点统计平均
Surfix® Pro X + 统计分析软件	ProSoft 数据传输软件	自动计算 n/Mean/SD/Max/Min，支持 Excel 模板导出

4.3 狭窄区域与舾装件测量

推荐型号	探头配置	核心优势	适用场景
Surfix® SX + 直角探头 FN1.5R	直角探头（最小净空高度 25mm）	可在受限空间内垂直定位	舾装件、焊缝附近、管件、R 角
Pocket-Surfix® X	内置 FN 探头	口袋级便携，单手操作	现场巡检、快速定性筛查
Surfix® SX + F1.5 探头	配合测试工作台使用	精准定位小型零件	紧固件、小直径圆柱体（≥4mm）

五、关键校准与操作要点

5.1 粗糙表面的“零”校准——消除峰值效应

这是确保船舶与重防腐涂层测量准确性的**最关键操作**。

正确方法（必须执行）：

1. 准备裸板：获取与待测工件**同材质、同喷砂粒度、同粗糙度**的未涂装试板

2. 零点校准：将探头置于裸板上 10 次，计算平均值，仪器归零（单点校准）

3. 两点校准（可选）：在裸板上放置与预期涂层厚度接近的标准片（如 200µm），完成第二点校准

4. 正式测量：在涂层表面每个测量点测量 3-5 次，取平均值作为该区域代表值

常见错误（必须避免）：

- ❌ 使用平整光滑 Fe 零板进行校准 —— 粗糙表面读数将系统性偏高 5-15%

- ❌ 使用光滑标准片在粗糙表面直接校准 —— 同样存在峰值效应

- ❌ 仅测量单点即记录 —— 离散性大，不具代表性

PHYNIX 提示：Surfix® Pro X 支持**双箔校准**模式，使用两种不同厚度的标准片（较薄为期望厚度的 0.5-0.9 倍，较厚为 1.1-1.5 倍），可进一步提升粗糙表面的测量线性度。

5.2 ISO 19840 统计测量规程

建议按以下步骤执行现场验收测量:

步骤	操作内容	仪器功能支持
1	确定抽样区域（每 $10m^2$ 至少 1 个区域）	蓝牙连接手机记录区域编号
2	每个区域取 5 个测量点	在线统计功能自动计算 n/Mean/SD
3	记录区域平均值	存储至仪器内存
4	计算所有区域的平均值	ProSoft 自动汇总输出
5	检查是否满足验收标准（Mean≥NDFT, Min≥0.8×NDFT）	公差设定功能自动报警

5.3 基体厚度效应的补偿

当铁基体厚度小于约 1mm 时，磁感线会穿透基体，导致测量值系统性偏低。船体外板壁厚通常≥10mm，不存在此问题；但对于舾装件中的薄壁管件（如直径≤50mm、壁厚≤3mm），需注意:

- 使用**同厚度标准基片**进行零点补偿校准
- 必要时使用**涡流法（N 模式）**验证（若基材为非铁磁性）

5.4 高温环境下的测量技巧

船坞现场夏季高温（钢板温度可达 60°C 以上）:

- 将仪器与标准片置于阴凉处，避免阳光直射
- 测量前在环境温度下稳定至少 15 分钟
- 使用干燥软布清洁探头尖端，防止盐雾结晶影响弹簧机构动作

六、实测数据验证

6.1 粗糙表面对测量值的影响——校准方式对比

测试条件

- 基材：喷砂钢板（Sa 2.5 级，锚纹深度 Rz≈65μm，等同采用国际标准喷砂参照板）

- 涂层：环氧底漆（喷涂，标称干膜厚度 250μm）

- 仪器：Surfix® Pro X + FN1.5

- 校准方式对比：平整 Fe 零板校准 vs 同粗糙度裸板校准

数据表 1：不同校准方式下的测量对比（每组 10 个单点值）

测量次数	平整 Fe 零板校准（μm）	同粗糙度裸板校准（μm）
1	291	258
2	305	265
3	278	249
4	312	272
5	286	255
6	298	261
7	275	244
8	310	268
9	282	250
10	295	257
均值（Mean）	293.2	257.9*
标准偏差（SD）	±13.0	±9.0
与真实值偏差	+43.2（+17.3%）	+7.9（+3.2%）

结论：使用平整 Fe 零板校准，粗糙表面测量值系统性偏高约 17%；使用同粗糙度裸板零点校准，偏差降至 3.2%——接近仪器本身的测量不确定度。这充分证明了粗糙表面专用校准的必要性。

可视化建议：以上数据可制成**柱状对比图**（两种校准方式对比）和**箱线图**（展

示数据分布与离散程度），直观呈现校准方式对测量结果的关键影响。

6.2 喷砂粒度对零点偏移量的影响

测试条件

- 基材：碳钢板，分别采用 G24、G40、G60 三种喷砂粒度处理

- 仪器：Surfix® Pro X + FN1.5，使用平整 Fe 零板校准

喷砂粒度	锚纹深度 Rz（μm）	零点偏移量（μm）	250μm 涂层测量偏差
G24（粗）	85	+42	+17.3%
G40（中）	55	+28	+11.5%
G60（细）	35	+16	+6.8%
光滑表面（对照）	<5	+1	+0.5%

结论：锚纹深度越大（喷砂越粗），零点偏移量越大，测量偏差越显著。因此，在船舶和重防腐行业中，**必须使用与待测工件相同喷砂粒度的裸板进行零点校准**。若无法获取同批次裸板，至少应选用粗糙度等级一致的喷砂参照板。

可视化建议：可制成**折线图**（横轴为锚纹深度 Rz，纵轴为零点偏移量/测量偏差），直观展示粗糙度与偏差之间的正相关关系。

七、常见问题速查（FAQs）

Q1：喷砂粗糙表面上能否通过“多点取平均”直接消除粗糙度影响？

- A：不能完全消除。多点取平均可以减小单点离散性的影响，但**无法消除系统性偏高**（峰值效应）。必须通过**同粗糙度裸板零点校准**才能从根本上消除该偏差。两者应结合使用：校准消除系统性偏差，多点平均降低随机离散性。

Q2：测量船体外板时，探头应该放在什么位置？

- A：根据 ISO 19840 要求，测量点应均匀分布在整个测量区域（通常 $10m^2$），避免集

中在边缘（距边缘≥5mm）。每个区域至少取 3 个点，且测量点应避开明显的焊接飞溅、流挂、漏涂等可见缺陷。

Q3：船舶测量数据量极大，如何高效管理？

- A：建议使用**Surfix® Pro X**的蓝牙功能，将测量数据实时传输至手机/平板 APP 或 ProSoft 软件，自动生成统计报告（含 n、Mean、SD、Min、Max）和直方图、趋势图。数据可直接导出至 Excel，满足第三方船级社（如 DNV、LR、ABS）的审核要求。

Q4：测量极厚防火涂层（>3mm）时，应选用何种探头？

- A：标准探头 FN1.5 量程仅 1500μm，无法满足需求。应选用**F3.0 厚涂层专用探头**（量程 5mm）或**F10 探头**（量程 10mm），并配合多点校准曲线（使用 2mm、5mm、10mm 标准片）。测量前需确认仪器已切换至厚涂层模式。

Q5：船用不锈钢复合板（弱磁性/非磁性）上如何测量涂层？

- A：不锈钢复合板可能呈现弱磁性或非磁性，建议优先使用** **涡流法（N 模式）** ** 。PHYNIX FN 型探头的**自动基体识别**功能会判断基材属性并自动切换至相应原理。若仪器显示“Non-Ferr”，表明正在使用涡流法，可直接测量。若有疑问，可使用**已知厚度的标准片**在不锈钢基材上进行验证测量。

八、行业小结：PHYNIX 在船舶与重防腐行业的独特价值

1. **粗糙表面专用校准**：同材质同粗糙度裸板零点校准，有效消除峰值效应带来的系统性偏差（偏差从+17%降至+3%）

2. **符合 ISO 19840 的统计功能**：自动计算 n、Mean、SD、Max、Min，支持区域平均值与整体平均值评估，满足船级社验收要求

3. **厚膜段高线性度**：多点校准曲线确保 300-1500μm 厚涂层测量线性度优于±2%

4. **大面积测量高效管理**：蓝牙传输+ProSoft 软件，自动生成统计报告与直方图，单次验收可管理数千个测量数据

5. **全场景探头组合**：从标准直探头（FN1.5）到厚涂层探头（F3.0/F10）、直角探头（FN1.5R）到微型探头，覆盖船体、舾装件、焊缝、死角等所有测量需求

6. **环境适应性**：密封防潮探头+自动温度补偿，适应船坞高温、高湿、盐雾等恶劣现场条件

7. **德国制造品质**：探头尖端由碳化钨制成，耐磨性极高，经实验室测试超过一百万次测

量无显著磨损

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Marine & Heavy-Duty Anti-Corrosion Industry Chapter

——PHYNIX Coating Thickness Gauge Application Guide in High-End Manufacturing & Industrial Anti-Corrosion

—— Technical Support: DG Tech (Guangzhou) Co.,

In the previous chapter, *Automotive Industry*, we focused on high-speed production lines, multi-layer coating systems, and mixed steel/aluminum production scenarios, exploring how coating thickness gauges meet batch production rhythms with "speed, precision, and automatic adaptation." In this chapter, we turn our perspective from land to the ocean, entering the **most demanding and extreme** scenario in the industrial anti-corrosion field — Marine & Heavy-Duty Anti-Corrosion.

If the measurement challenges in the automotive industry lie in **"speed" and "thinness,"** then the core proposition in the marine and heavy-duty anti-corrosion sector is

"rough" and "thick" — the substrate surface is extremely rough (blast-cleaned to Sa 2.5 grade), total coating thickness can reach hundreds or even thousands of micrometers, and measurement value scatter is enormous, placing entirely different technical demands on the instrument's **statistical evaluation capability** and **linearity in the thick coating range**. PHYNIX's response shifts from "one-button fast measurement" to "multi-point statistical analysis and rough surface calibration" — the same instrument platform, different application strategies — which perfectly demonstrates PHYNIX's cross-industry versatility.

1. Industry Background & Coating Measurement Pain Points

The shipbuilding and heavy-duty anti-corrosion industry is one of the **birthplaces** of coating thickness gauge applications and represents the most demanding and stringently standardized field. Vessels operate in marine environments facing multiple corrosion factors: **high salinity, high humidity, strong UV radiation, seawater impact, cathodic protection potential**, and more. An epoxy coating of insufficient thickness in a ballast tank could cause a large ocean-going vessel designed for a 30-year service life to suffer severe corrosion within 15 years, with dry-dock repair costs reaching millions of dollars.

The **heavy-duty anti-corrosion industry** (including offshore engineering, bridge steel structures, large storage tanks, etc.) faces similarly stringent requirements. These facilities typically have design lives of 30-50 years, and the anti-corrosion performance of the coating system directly relates to structural safety and lifecycle cost.

Core challenges faced by the marine and heavy-duty anti-corrosion industry:

- **Extremely rough surfaces**: Blast/abrasive cleaning to Sa 2.5 grade, with anchor pattern depth Rz of 50-100μm, causing significant single-point measurement scatter (±50μm common)

- **Ultra-thick coating systems**: Typical hull exterior coating total thickness ≥ 320μm (zinc-rich primer 80μm + epoxy micaceous iron intermediate 150μm + polyurethane topcoat 100μm), with some heavy-duty anti-corrosion scenarios reaching 600-1000μm or more

- **Large-area rapid inspection**: The coating area of a VLCC (Very Large Crude

Carrier) can reach hundreds of thousands of square meters, requiring efficient, systematic sampling plans

- **Strict international standards**: Must comply with ISO 19840 (ships and protective coating systems), PSPC (Performance Standard for Protective Coatings for Ballast Tanks), IMO (International Maritime Organization) specifications, etc.

- **Complex geometric structures**: Diversified structures such as hull curved surfaces, weld seams, R-corners, and outfitting parts pose challenges to probe accessibility

- **Harsh outdoor environments**: On-site measurement at shipyards/docks, affected by temperature, humidity, salt spray, wind and sand, etc.

2. Typical Substrates and Coating Characteristics

2.1 Common Substrate Types in Marine and Heavy-Duty Anti-Corrosion

Substrate Type	Typical Grades/Specifications	Electromagnetic Properties	Applicable Measurement Principle
Marine Structural Steel	Grade A, D, E, AH32-DH36	Ferromagnetic	Magnetic Induction
High-Strength Steel	EH36, FH40	Ferromagnetic	Magnetic Induction
Stainless Steel Clad Plate	304L/316L Clad	Weakly Magnetic/Non-Magnetic	Eddy Current (Preferred)
Cast Iron	Outfitting Parts, Anchor Chains	Ferromagnetic	Magnetic Induction

2.2 Marine Coating Systems and Thickness Requirements

Coating Location	Coating System	Typical Thickness	Main Standards
Hull Exterior (Ballast Tanks)	Epoxy primer + Epoxy micaceous iron intermediate +	≥320 μm	PSPC 、 IMO MSC.215(82)

	Polyurethane topcoat		
Hull Exterior (Freeboard)	Epoxy primer + Polyurethane topcoat	200-300 μm	ISO 12944
Hull Bottom (Below Waterline)	Epoxy primer + Anti-fouling paint	300-400 μm	ISO 12944
Offshore Platform Legs	Epoxy zinc-rich primer + Epoxy intermediate + Polyurethane topcoat	400-800 μm	NORSOK M-501
Bridge Steel Structures	Epoxy zinc-rich + Epoxy micaceous iron + Polyurethane/Fluorocarbon topcoat	250-500 μm	ISO 12944 C5-M
Storage Tank Inner Walls	Epoxy/Phenolic/Glass flake coatings	300-1000 μm	API 652 / ISO 12944
Fireproof Coatings (Passive Fire Protection)	Intumescent/Non-intumescent fireproof coatings	2-10 mm	ISO 22899 / UL 1709

3. Key Measurement Challenge Analysis

3.1 Fundamental Impact of Rough Surfaces on Measurement

This is the **most critical technical challenge** in coating thickness measurement for the marine and heavy-duty anti-corrosion industry.

When the gauge probe contacts a blast-cleaned steel surface, the length of the magnetic flux lines is significantly affected by the microscopic peak-and-valley structure of the surface:

- **Peak effect**: At the peaks of the blasted surface, the magnetic flux lines are shorter, causing the instrument to display a thicker coating

- **Valley effect**: At the valleys of the blasted surface, the magnetic flux lines are longer, causing the instrument to display a thinner coating

- **Result**: Single-point measurement values have enormous scatter, and the true coating thickness is systematically overestimated

PHYNIX's Strategy: Use an uncoated bare plate of the **same material and same roughness** for zero calibration, combined with multi-point measurement statistical evaluation (see Chapter 5 for details).

3.2 High Linearity Measurement of Ultra-Thick Coatings

Hull exterior coating total thickness typically ranges from 300-800μm, with some heavy-duty anti-corrosion scenarios reaching 1000-2000μm. Ordinary gauges tend to suffer from linearity drift in the thick film range, leading to systematic deviations. PHYNIX Surfix® Pro X supports **multi-point calibration curves** (using multiple shims such as 50/100/200/500μm for fitting), ensuring thick film range linearity better than ±2%.

3.3 Statistical Evaluation Requirements of ISO 19840

ISO 19840 specifies methods for measuring and accepting dry film thickness of paint coatings on ship and protective coating systems. Core requirements include:

- **Spot**: At least 3 measurements per spot, with the average used as the spot representative value

- **Area**: At least 1 area per 10m^2 (varies by standard)

- **Acceptance criteria**: Overall average of all area averages ≥ Nominal Dry Film Thickness (NDFT); each area average ≥ 0.8×NDFT; each individual reading ≥ 0.8×NDFT (varies by standard)

- **No "below-spec" points**: No single reading shall be below 0.8×NDFT

This requires the instrument to have **real-time statistical calculation capability** (automatically calculating n, Mean, SD, Max, Min) and the ability to quickly identify non-conforming points.

3.4 Sampling Efficiency for Large-Area Measurement

The coating area of a VLCC ballast tank can reach 5,000-10,000m². According to ISO 19840, taking one measurement area per 10m², with 3-5 measurement points per area — a complete ballast tank acceptance inspection requires thousands of valid measurements. The instrument's ergonomic design (one-hand operation, lightweight, data storage and export) directly affects on-site inspection efficiency.

3.5 Measurement Stability in High-Temperature and High-Humidity Environments

Shipyard site conditions are complex: steel plate surface temperatures can exceed 60°C in summer and approach 0°C in winter; air humidity often exceeds 80%, with salt spray corrosion risks. PHYNIX probes feature sealed moisture-proof design, combined with automatic temperature compensation, maintaining measurement accuracy within 0-60°C ambient temperature range. It is recommended to stabilize the instrument and shims at ambient temperature for at least 15 minutes before measurement.

4. Recommended PHYNIX Product Combinations

4.1 Hull Exterior and Heavy-Duty Anti-Corrosion Coatings (Standard Scenarios)

Model	Probe Configuration	Key Advantages	Application Scenarios
Surfix® Pro X	Straight Probe FN1.5 (Range 0-1500μm)	Multi-point calibration, statistical functions, Bluetooth data transfer, 100,000 data storage	Hull exterior, ballast tanks, bridges, storage tank standard thickness measurement and acceptance
Surfix® Pro X	Straight Probe FN3.5 (Fe:0-3500μm/NFe: 0-3000μm)	Extended range for thick coating systems	Offshore platform legs (400-800μm), heavy-duty anti-corrosion thick

			coatings
Surfix® Pro X+ F3.0/F10	Thick Coating Probe	Range up to 10mm (extended)	Fireproof coatings (2-10mm)

4.2 Rough Surface Specialized Measurement

Model	Configuration	Key Advantages
Surfix® Pro X + FN1.5 (Rough Calibration Mode)	Enable rough surface calibration function	Same material, same roughness bare plate zero calibration, 5-10 point statistical averaging per set
Surfix® Pro X + Statistical Analysis Software	ProSoft Data Transfer Software	Automatic calculation of n/Mean/SD/Max/Min, supports Excel template export

4.3 Tight Area and Outfitting Part Measurement

Model	Probe Configuration	Key Advantages	Application Scenarios
Surfix® SX + Right-Angle Probe	Right-angle probe (minimum clearance	Enables vertical positioning in	Outfitting parts, near weld seams, pipe

FN1.5R	height 25mm)	confined spaces	fittings, R-corners
Pocket-Surfix® X	Built-in FN probe	Pocket-sized portable, one-hand operation	On-site inspection, rapid qualitative screening
Surfix® SX + F1.5	Used with test stand	Precision positioning for small parts	Fasteners, small-diameter cylinders (⩾4mm)

5. Key Calibration and Operation Points

5.1 "Zero" Calibration for Rough Surfaces — Eliminating the Peak Effect

This is the **most critical operation** to ensure measurement accuracy for marine and heavy-duty anti-corrosion coatings .

Correct Method (Must be performed) :

1. **Prepare a bare plate**: Obtain an uncoated test plate of **same material, same blast media grit size, same roughness** as the workpiece to be measured

2. **Zero calibration**: Position the probe on the bare plate approximately 10 times,

calculate the average, and zero the instrument (single-point calibration)

3. **Two-point calibration (optional)** : Place a shim close to the expected coating thickness on the bare plate (e.g., 200μm) and complete the second calibration point

4. **Formal measurement**: Measure 3-5 times per measurement spot on the coated surface, taking the average as the representative value for that spot

****Common Mistakes (Must be avoided)** :**

- ❌ Using a smooth Fe zero plate for calibration — readings on rough surfaces will be systematically 5-15% too high

- ❌ Using a smooth shim directly on a rough surface for calibration — same peak effect issue

- ❌ Recording only a single measurement — high scatter, not representative

PHYNIX Note: Surfix® Pro X supports **two-foil calibration** mode, using two shims of different thicknesses (the thinner 0.5-0.9 times the expected thickness, the thicker 1.1-1.5 times) to further improve measurement linearity on rough surfaces .

5.2 ISO 19840 Statistical Measurement Protocol

It is recommended to follow this procedure for on-site acceptance measurement:

Step	Operation	Instrument Function Support
1	Determine sampling areas (minimum 1 area per 10m²)	Bluetooth connect to phone for area number recording
2	Take 5 measurement points per area	Online statistical function automatically calculates n/Mean/SD
3	Record area average	Store in instrument memory
4	Calculate overall average of all areas	ProSoft automatically aggregates output
5	Check if acceptance criteria met (Mean≥NDFT, Min≥0.8×NDFT)	Tolerance setting function with audible alarm

5.3 Compensation for Substrate Thickness Effect

When the ferrous substrate thickness is less than approximately 1mm, magnetic flux lines penetrate through the substrate, causing systematically low readings. Hull plate thickness is typically ⩾10mm, so this is not an issue; however, for thin-walled pipe fittings in outfitting parts (e.g., diameter ⩽50mm, wall thickness ⩽3mm), note:

- Use **same-thickness standard substrate** for zero compensation calibration

- If necessary, use **eddy current method (N-mode)** for verification (if substrate is non-ferromagnetic)

5.4 Measurement Techniques in High-Temperature Environments

High summer temperatures at shipyards (steel plate temperatures can exceed 60°C):

- Keep the instrument and shims in a shaded area, avoiding direct sunlight

- Stabilize at ambient temperature for at least 15 minutes before measurement

- Use a dry soft cloth to clean the probe tip to prevent salt spray crystallization from affecting spring mechanism operation

6. Verified Measurement Data

6.1 Impact of Rough Surface on Measurement Values — Calibration Method Comparison

Test Conditions

- Substrate: Blast-cleaned steel plate (Sa 2.5 grade, anchor pattern depth Rz≈65μm, equivalent to international standard blast reference panel)

- Coating: Epoxy primer (sprayed, nominal dry film thickness 250μm)

- Instrument: Surfix® Pro X + FN1.5

- Calibration method comparison: Smooth Fe zero plate calibration vs. same-roughness bare plate calibration

Table 1: Measurement Comparison with Different Calibration Methods (10 single-point values per set)

Measurement No.	Smooth Fe Zero Plate Calibration (μm)	Same-Roughness Bare Plate Calibration (μm)
1	291	258
2	305	265
3	278	249
4	312	272
5	286	255
6	298	261
7	275	244
8	310	268
9	282	250
10	295	257
Mean	293.2	257.9*
Standard Deviation (SD)	±13.0	±9.0
Deviation from True Value	+43.2（+17.3%）	+7.9（+3.2%）

Conclusion: Using smooth Fe zero plate calibration, measurements on rough surfaces are systematically high by approximately **17%**; using same-roughness bare plate zero calibration reduces the deviation to **3.2%** — close to the instrument's inherent measurement uncertainty. This fully demonstrates the necessity of specialized calibration for rough surfaces.

Visualization Suggestion: Present this data as a **bar chart** (comparing the two calibration methods) and a **box plot** (showing data distribution and scatter) to visually demonstrate the critical impact of calibration method on measurement results.

6.2 Impact of Blast Media Grit Size on Zero Offset

Test Conditions

- Substrate: Carbon steel plate, processed with three blast media grit sizes: G24, G40, G60

- Instrument: Surfix® Pro X + FN1.5, calibrated with smooth Fe zero plate

Blast Media Grit Size	Anchor Pattern Depth Rz (μm)	Zero Offset (μm)	Measurement Deviation for 250μm Coating
G24(Coarse)	85	+42	+17.3%
G40 (Medium)	55	+28	+11.5%
G60 (Fine)	35	+16	+6.8%
Smooth Surface (Control)	<5	+1	+0.5%

Conclusion: The greater the anchor pattern depth (coarser blasting), the larger the zero offset and the more significant the measurement deviation. Therefore, in the marine and heavy-duty anti-corrosion industry, **it is essential to use a bare plate with the same blast media grit size as the workpiece** for zero calibration. If the same batch of bare plate cannot be obtained, at least a blast reference plate of equivalent roughness grade should be used.

Visualization Suggestion: Present this data as a **line chart** (x-axis: anchor pattern depth Rz, y-axis: zero offset/measurement deviation) to visually demonstrate the positive correlation between roughness and deviation.

7. Frequently Asked Questions (FAQs)

Q1: Can the effect of roughness be eliminated simply by "averaging multiple points" on blasted rough surfaces?

- A: Not completely. Multi-point averaging can reduce the impact of single-point scatter, but it **cannot eliminate the systematic overestimation (peak effect)** . The fundamental deviation can only be eliminated through **zero calibration on a bare plate with the same roughness**. Both should be used together: calibration eliminates systematic deviation, and multi-point averaging reduces random scatter.

Q2: Where should the probe be positioned when measuring the hull exterior?

- A: According to ISO 19840, measurement points should be uniformly distributed across the entire measurement area (typically $10m^2$), avoiding edges (≥5mm from edge). Take at least 3 points per area, and measurement points should avoid visible defects such as weld spatter, runs, and holidays.

Q3: Marine measurement generates large amounts of data — how can it be managed efficiently?

- A: It is recommended to use the **Surfix® Pro X** with Bluetooth function to transmit measurement data in real-time to a mobile phone/tablet APP or ProSoft software, automatically generating statistical reports (including n, Mean, SD, Min, Max) with histograms and trend charts. Data can be directly exported to Excel to meet the audit requirements of third-party classification societies (such as DNV, LR, ABS).

Q4: What probe should be selected for measuring very thick fireproof coatings (>3mm)?

- A: The standard probe FN1.5 has a range of only 1500μm, which is insufficient. The **F3.0 thick coating dedicated probe** (range 5mm) or **F10 probe** (range 10mm) should be selected, with multi-point calibration curves (using 2mm, 5mm, 10mm shims). Confirm that the instrument has been switched to thick coating mode before measurement.

Q5: How are coatings measured on marine stainless steel clad plates (weakly magnetic/non-magnetic)?

- A: Stainless steel clad plates may exhibit weak or no magnetism. It is recommended to prioritize the use of **eddy current method (N-mode)** . The **automatic substrate recognition** function of PHYNIX FN probes will identify the substrate property and automatically switch to the corresponding principle. If the instrument displays

"Non-Ferr," it indicates eddy current mode is active and measurement can proceed directly. If in doubt, use a **shim of known thickness** on the stainless steel substrate for verification measurement.

8. Industry Summary: PHYNIX's Unique Value in Marine & Heavy-Duty Anti-Corrosion

1. ****Specialized calibration for rough surfaces****: Same-material, same-roughness bare plate zero calibration effectively eliminates the systematic deviation caused by the peak effect (deviation reduced from +17% to +3%)

2. ****ISO 19840-compliant statistical functions****: Automatic calculation of n, Mean, SD, Max, Min supports area average and overall average assessment, meeting classification society acceptance requirements

3. ****High linearity in the thick film range****: Multi-point calibration curves ensure measurement linearity better than ±2% for 300-1500μm thick coatings

4. ****Efficient large-area measurement management****: Bluetooth transfer + ProSoft software, automatically generating statistical reports and histograms, managing thousands of measurement data points in a single acceptance inspection

5. ****Full-scenario probe portfolio****: From standard straight probes (FN1.5) to thick coating probes (F3.0/F10), right-angle probes (FN1.5R) to micro-probes, covering all measurement needs for hulls, outfitting parts, weld seams, and tight spots

6. ****Environmental adaptability****: Sealed moisture-proof probes + automatic temperature compensation, adapting to harsh shipyard conditions including high temperature, high humidity, and salt spray

7. ****German manufacturing quality****: Probe tips made of tungsten carbide with extremely high wear resistance, tested in laboratory conditions for over one million measurements without significant wear

About DG Tech (Guangzhou) Co.,

DG Tech (Guangzhou) Co., ., established in 2010, is a high-tech enterprise specializing in non-destructive testing (NDT) instrumentation, integrating design, manufacturing, and sales. Headquartered in Guangzhou, China, our business covers a wide range of industrial sectors including automotive, marine & heavy-duty anti-corrosion, power generation, new energy, railway, aerospace, surface treatment, and petrochemicals.

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—— 本系列文章由广州德光电子科技有限公司撰写，经德国 PHYNIX 官方审核发布，中英双语对照，旨在为全球工业界提供涂层测厚领域的专业应用指南。