Pipeline In-line Inspection
管道内检测技术

• Bill Gu

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Who am I?

Bill Gu
Principal Consultant
Integrity Services Division
Bakerhughes
Bill.gu@bakerhughes.com

Ph.D, Registered professional Engineer in Canada. Over 20 years experience in pipeline integrity management, specialising in ILI technology, defect assessment methodologies, risk and reliability assessment, corrosion growth studies and advanced data management.

Is PPS commercial leader for China and a Principal Consultant in the Integrity Services Division at Bakerhughes. He is a member of APEGGA, ASME, ISO, PRCI and NACE.
提纲

1. 内检测的发展历史
2. 常规内检测技术
3. 如何选择适合的检测技术
4. 超声波与漏磁检测的区别
5. 最新内检测发展趋势
内检测的发展历史
History of ILI - 1960s

- **Magnetic Flux Leakage (MFL) tool**: Developed in 1965 by Tuboscope to detect areas of metal loss
  - First tool had 12 sensors, with 90° arc on bottom of pipe (low resolution)
  - Detected internal corrosion on crude oil pipelines
  - Tape Recorder used as data storage
History of ILI – 1960s

- **Kaliper** tool first developed by TDW in late 1960s
- Provided course measurements of dents and out-of-roundness pipe
- Single channel recorder with sensors mounted on inside of rear cups
- Data recorded on pressure sensitive paper inside the tool
History of ILI – 1970s and 1980s

- 1970s - British Gas (BG) invests in their own high-resolution MFL inspection tool. Vetco and Tuboscope succeed in developing new MFL tools.

- Instead of 12 sensors per tool, these new tools had approximately 1.27 cm (0.5 in) spacing, permanent magnets, and inner diameter/outer diameter (ID/OD) discrimination.

- Inspection tools could detect and size anomalies
History of ILI – 1970s and 1980s

- **Deformation (DEF) tools** improve from single channel sensors to 6-12 channel sensors.
- Nearly every vendor develops DEF tool with various levels of resolution.
History of ILI – 1990s and 2000s

- **Ultrasonic Crack Detection (UTCD):** Pipeline Integrity International (PII) develops first tool in 1994 for axial cracks.

- **Circumferential MFL (CMFL):** developed for axial metal loss and crack-like defects

- **Combo-tools:** are introduced using multiple technologies on a single tool – DEF + MFL
History of ILI – 1990s and 2000s

- **Electromagnetic Acoustic Transducer (EMAT):**
  - Rosen and GE-PII develop first EMAT tools - crack inspections on gas transmission pipelines

![Image of EMAT tool](image1)

Photo: geolandgas.com

- TDW develops first EMAT tool in late 2000s

![Image of EMAT tool](image2)

Photo: rosen-group.com
History of ILI – 1990s and 2000s

- **Speed Control tools** – allows pipelines to operate at full rate while ILI tool travels at a slower rate.

- **Mapping (XYZ) tools** – provides GPS coordinates of pipeline

- **Robotic tools** – difficult to pig pipelines
  - Unbarred tees, low/no-flow, diameter changes, mitre bends
BakerHughes内检测器系列研发历史

1977年开发高分辨率漏磁检测器，1998年增加GIS定位测绘功能。

1985年研制超声波壁厚腐蚀检测器。

1992年研制用于输气管线的弹性波裂纹检测器。

1994年开发出高分辨率超声波裂纹检测器，用于液体管线。

1999年研制出环向漏磁检测器，用于轴向狭长腐蚀和严重的直焊缝裂纹缺陷。

2002年开发出高分辨率EMAT裂纹检测器，用于输气管线。

2008第四代漏磁检测器开发

2005多变径可伸缩检测器

2005 Ultra ScanDuo相控阵检测器

2012轴向应变检测器AXISS
• 常规内检测技术
MagneScan 漏磁检测器

- *Magnetic Flux Leakage*

- 主要适用于:
  - 金属损失探测——管道内外腐蚀等
  - 油气管道都适用

- 其次还可以探测
  - 环焊缝缺陷
  - 管道金属外接物
  - 管道材质硬疤
漏磁检测器原理

- 强磁铁产生高磁通量通过管壁
- 如下情况会使磁力线产生扭曲：
  - 管壁中有金属损失点
  - 如果有金属接近管壁
  - 材质变化
- 传感器会接受到磁通量的变化
MagneScan 漏磁检测器

Type 2 sensor array
Odometer

Drive cups

Type 1 sensor array

Support wheels

Permanent Magnet Brushes

Leading Magnetic Vehicle

3” - 56” 英寸
56” MFL Tool

56” MagneScan
36/48 英寸双径检测器
漏磁检测器可以探测到的缺陷

Corrosion

Contacting Metal Objects

Weld defects

Dents & Gouging
超声波壁厚检测器USWM

• **Ultrasound - Time of Flight**

• **主要适用于**
  • 金属损失探测——管道内外腐蚀
  • 输油或液体管线

• **其次还可以探测**
  • 夹层缺陷
  • 氢鼓泡
UltraScan WM

金属损失的直接测量
精度较高±0.4mm
有效区分内外腐蚀
可探测除腐蚀外的管体加工缺陷如夹层等
只适用于输油管线
费用较漏磁检测器昂贵约20%
超声波原理

external

internal

pipe wall

wt

UltraScan sensor

SO

SO = stand-off

wt = wall thickness
外腐蚀信号
内腐蚀信号
夹层缺陷信号
Ultrasound - 45º Shear Wave
主要适用于
管体应力腐蚀裂纹
还可探测到
焊缝的疲劳和收缩裂纹
超声波裂纹检测器原理
SCC 焊缝附近的应力腐蚀裂纹
检测器发射
环向漏磁检测器

TranScan
Transcan

• 漏磁原理 – 环向磁场

• 主要适用于:
  • 轴向狭长金属损失缺陷

• 其次还可探测:
  • 直焊缝裂纹
轴向焊缝缺陷引起的爆管事故
缺陷几何尺寸对传统漏磁检测器磁场变化的影响

环向缺陷对磁场敏感，信号强

轴向缺陷信号弱
缺陷几何尺寸对环向漏磁检测器磁场变化的影响

环向缺陷信号较弱

轴向缺陷信号较强
环向检测器磁场分布
12” TFI tool
EmatSCAN
高精度输气管线裂纹检测EMAT技术

Conventional Ultrasonic technology

Piezoelectric Crystal

Liquid coupling

Pipe Wall

EMAT technology

Permanent Magnet

Air Gap

Ultrasonic Sources

RF Coil

Pipe Wall
EMAT Principle of Operation:

A high-frequency coil induces eddy currents in the material. The surface currents in the presence of the magnetic field generate a Lorentz force that is transferred to the atomic lattice of the material. This force produces an ultrasonic wave that propagates through the material.
Crack detection in gas pipeline

- UltrScan® CD tool
- Batch-Liquid
- ~ 500 m
- EmatScan® CD tool
- Couplant-Free
Detection of internal and external crack-like defects
System of interacting EMAT sensors
Sensor Arrangement per Sensor Skid

- **Guide Wheel x 4** to maintain 3mm gap between magnet and pipe wall
- **SH Transmit**
- **RH Sensor**
- **SH Receive**
- **Magnet to reduce motion induced Barkhausen noise, increase S/N ratio**
- **More wheels to share loading**
- **Brush to remove debris**
- **TS Sensor for WT**

More wheels to share loading
Elastic Wave
Elastic Wave

- Based on ultrasonic technology
- Waves injected at 65° travel circumferentially around pipe
- Designed to detect long seam fatigue, SCC, lack of fusion & hook cracks
- Transducers in fluid filled wheels therefore can run in gas pipelines
测绘与应变评估
ScoutScan 定位检测器

- 检测器尺寸范围 12-56英寸
- 实现每节环焊缝定位
- 定位报告间隔为5cm
- 经济实用，可与变形和腐蚀检测器配合使用
Honeywell 位移测量装置

Mapping Unit
1:2000 Pig Travel
1:4000 Reference spacing

Additional error sources
GPS Survey
Reference correlation
Inertial Measurement Unit (IMU)

• IMU measures a pig’s movement in 3D:
  • 3 Gyroscopes measure rotation.
  • 3 accelerometers measure acceleration and gravity
• 加速测量仪测量加速度和重力
位移测量
精确定位的好处：

- 准确的缺陷定位
  - 合理制定开挖计划减小开挖成本
  - 准确发现风险点
- 数据管理
- 管线移动监测
完整性数据整合

- GIS地理信息系统把图像数据和检测数据统一起来
- 加强对管道特征的理解
- 便于管道数据管理，提高效率
如何选择适合的检测技术
如何选择适合的检测技术

Tool Development and PipeLine Inspection – common set of factors

- most appropriate technology 最适合的技术
- most appropriate sensor 最适合的传感器
- tool operating window 工具操作窗口
- design parameters 设计参数
- analysis tools 分析工具
- decision support 支持工具
选择合适的管道检测器-管道本身出发

<table>
<thead>
<tr>
<th>性能</th>
<th>描述</th>
</tr>
</thead>
<tbody>
<tr>
<td>直径</td>
<td>单一管径的检测器；双管径的检测器。</td>
</tr>
<tr>
<td>长度</td>
<td>备用电池模块或者存储器可以有效的完成单程道的检测。</td>
</tr>
<tr>
<td>壁厚</td>
<td>检测范围的选择可达到 25-30mm，可以通过: 80-85% of API OD</td>
</tr>
<tr>
<td>流速</td>
<td>大直径高压力天然气管线中，检测器运行可达到 5m/s；速度控制系统可以达到 12m/s</td>
</tr>
<tr>
<td>温度</td>
<td>0-40°C，而且可选择达到 60°C 连续或者 80°C 瞬态</td>
</tr>
<tr>
<td>压力</td>
<td>最大可达到 220 bar，可以改进低压力(＜40 bar)天然气管道检测器的动力性</td>
</tr>
</tbody>
</table>
管道缺陷威胁 ... 来自腐蚀

运行者需要的工艺技术可以提供：
- 精确的尺寸
- 高识别
- 可靠的位置
- 腐蚀增长
- 风险评估
- 最小程度的减少停产

腐蚀 ... 当今最关心的问题
裂纹是......很快增加的问题

运行者需要的技术可以提供：
• 临界缺陷检测
• 亚临界缺陷检测
• 可靠位置
• 风险评估
• 最小程度的减少停产

管道缺陷威胁...裂纹
Pipeline Defects

1. Geometry Defects
   - diameter reduction
   - dent
   - buckle
   - ovality

2. Metal Loss
   - ext. & int. metal loss
   - pitting
   - manuf. related wall thickn. variation
   - channelling

3. Cracks
   - int. & ext. crack
   - lamination
   - hydrogen induced cracking (HIC)
   - crack field
Pipeline Defects

The right technology for every integrity challenge

New hire and channel partner product training
new hire and channel partner product training

The right technology for every integrity challenge

<table>
<thead>
<tr>
<th>Application Specifics</th>
<th>Metal Loss Features</th>
<th>Crack Features</th>
<th>Deformation &amp; Geometry</th>
<th>Integrity Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liquid medium</td>
<td>General corrosion</td>
<td>Hydrogen induced crack</td>
<td>Corrosion growth rate estimation (net)</td>
</tr>
<tr>
<td>UltraScan WMP</td>
<td>No through thickness measurement</td>
<td>Shallow grooves</td>
<td>Sheet crack</td>
<td>Flaw classification (CFI)</td>
</tr>
<tr>
<td>UltraScan DUO</td>
<td>Precise, direct wall-thickness measurement</td>
<td>Porous</td>
<td>Fatigue crack</td>
<td>Flaw detection (UT)</td>
</tr>
<tr>
<td>UltraScan CDP</td>
<td>One tool for metal loss and cracking</td>
<td>External corrosion</td>
<td>Circumferential crack</td>
<td>Flaw assessment (NDE)</td>
</tr>
<tr>
<td>EmatScan CD</td>
<td>Most accurate crack inspection (liquid)</td>
<td>Internal corrosion</td>
<td>Leak detection</td>
<td>Corrosion growth rate assessment (net)</td>
</tr>
<tr>
<td></td>
<td>Most accurate crack inspection (gas)</td>
<td>Hydrogen induced crack</td>
<td>Crack in root</td>
<td>Flaw mapping (NDE)</td>
</tr>
</tbody>
</table>

latest advancements
如何评判检测技术好坏

**Element 1 可靠准确的测量精度**
- A reliable and accurate measurement performance for detecting, discriminating and sizing

**Element 2**
- A comprehensive excavation program with accurate field and laboratory direct observation to evaluate ILI tool performance provide reliable data feedback to the ILI vendor for improvement.

**Element 3**
- A failure model /method with material testing data to prioritizing excavation investigation life cycle/re-inspection interval prediction 把内检测数据用于完整性评估，指导修复和再检测周期.
高精度的好处

高精度的结果意味着减少修复………….

图示了高分辨率和低分辨率的金属损失特征。
• 超声波与漏磁检测的区别

Which technology to use?
The right technology for every integrity challenge

<table>
<thead>
<tr>
<th>MULTIPLE THREATS</th>
<th>GEOHAZARD</th>
<th>THIRD PARTY DAMAGE &amp; GEOMETRY</th>
<th>MANUFACTURING &amp; CONSTRUCTION</th>
<th>CRACKING</th>
<th>CORROSION &amp; METAL LOSS</th>
<th>OPERATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal loss on pipe</td>
<td>Defects in oil field</td>
<td>Crack in pipeline</td>
<td>Dents on pipe</td>
<td>Crack in metal</td>
<td>Hydrogen induced cracks</td>
<td>Axial cracks</td>
</tr>
<tr>
<td>Best available</td>
<td>Fail-safe protection</td>
<td>Crack in pipeline</td>
<td>Dents on pipe</td>
<td>Crack in metal</td>
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</table>

- **UltraScan WMP**
  - Higher resolution, higher accuracy direct wall measurement

- **New MagnaScan™ SHARP & VECTRA GEMINI HC**
  - Superior accuracy to optimize MFL programs

- **New MagnaScan™ SHARP & VECTRA GEMINI**
  - High accuracy, repeatable MFL with caliper

- **New MagnaScan™ HR**
  - Next generation high resolution combination MFL inspection

- **MagneScan™ HR**
  - High resolution MFL inspection

March 7, 2020
MFL Technology
Robust and proven technology which has been in operation for 30+ years

Strengths

Operational
✓ Tolerant to debris (more so than UT), detection if debris ‘in’ corrosion
✓ Wide speed range: 0-5 m/s, specs also achieved at higher speeds
✓ 4-56”
✓ Up to 220 bar
✓ Combo technology: Metal loss, geometry & mapping in 1 run

Data
✓ Pinhole detection & sizing: spec from 5mm and seeing defects from 2mm in diameter
✓ Pits, general ML and circumferential defects
✓ Welds (girth & spiral): detection & sizing across weld area + recent circ crack specifications
✓ Defects in defects improvements in recent years

Weaknesses

Operational
• Preconditioning sometimes required in thick wall pipe
• Brush design not ideal for dual diameter applications

Data
• MFG discrimination: Laminations, midwall
• Not direct measurement of WT
• Wall thinning
• Channelling corrosion
UT wall measurement Technology

Robust and proven technology which has been in operation for 30+ years

**Strengths**

**Operational**
- ✓ Thick wall pipe up to 45mm
- ✓ Wide speed range: up to 2.5 m/s, specs also achieved at higher speeds
- ✓ lower differential pressure
- ✓ 6-52"

**Data**
- ✓ Direct WT measurement in mm
- ✓ Cladding
- ✓ Seamless pipe wt variations
- ✓ Lamination and Blisters, Manufactured and HIC
- ✓ Pinhole & pitting detection: spec defects from 1mm @ 5mm Ø
- ✓ Channelling corrosion

**Weaknesses**

**Operational**
- • Liquid medium required
- • Line cleanliness sensitivity
- • Pressure 120 bar

**Data**
- • Pitting sizing: spec from 8mm
- • Heavy seamless pattern can cause echo loss on older systems
Which Technology?

Both delivering accurate & reliable data.

**MFL:**
- Pinholes
- GW defects
- Challenges with pipeline cleanliness
- Higher speeds

**UT:**
- Actual WT measurement
- MFG discrimination
- Wall thinning / channel corrosion

MFL or UT
• 最新内检测发展趋势
内检测发展的趋势 ILI Threat Trends...

**Corrosion & Metal Loss**
- Large, North American operators primarily driving technology improvements
- Focus shifting away from general to complex corrosion and outliers -> ‘defect morphologies’
- Looking for increased confidence in gouges & metal loss in dents

**Cracks**
- SCC in Gas pipelines: US regulations driving sharp increase in EMAT inspections
- Girth Welds continue to be a challenge driving increase in IMU runs and bending strain assessments
- Axial strain measurement (AXISS) seen as an option to identify high risk areas
# Research Objectives

<table>
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<tr>
<th></th>
<th>Research Objective</th>
<th>Est. Timeline to meaningful impact</th>
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<tbody>
<tr>
<td>1</td>
<td>Develop and/or validate technology and analytical processes that are capable of characterizing pipeline material properties with sufficient accuracy for application in pipeline integrity assessments.</td>
<td>3 years</td>
</tr>
<tr>
<td>2</td>
<td>Develop and enhance ILI technology to reliably detect, size and characterize indications that may be harmful to the integrity of the pipeline.</td>
<td>5 years</td>
</tr>
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## Research Objectives

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<tbody>
<tr>
<td>3</td>
<td>Develop, evaluate and enhance NDE technologies and operator &amp; data analyst performance to define the condition and assess the integrity of pipeline, facilities and associated infrastructure from outside or above the pipeline or facility.</td>
<td>5 years</td>
</tr>
<tr>
<td>4</td>
<td>Improve the accuracy and application of Fitness for Service methodologies by reducing uncertainties. Define, understand and improve the key factors, including models that are involved in design, construction or integrity assessments of any component in systems covered by PRCI.</td>
<td>5 years</td>
</tr>
</tbody>
</table>
Technology Development Center - TDC
TDC Existing Capabilities

- Services available to PRCI members and nonmembers
  - Pull test facility for In-line Inspection tools
    - 24”, 16”, 12” & 8” pipe strings containing hundreds of fully characterized real & manufactured defects.
    - Main winch is capable of running consistent velocities from 1 mph to 11 mph while pulling over 5,000 lbs.
  - Liquid loop test facility
    - 12” & 6” nominal pipe utilizing water as the liquid medium
    - Variety of configurations ranging from easily piggable to "difficult to inspect"
    - Design incorporates the ability for continuous test cycles at a pressure of ANSI Class 150 (285 psi)
  - Large inventory of pipe Samples with real-world and manufactured defects
  - Qualification testing of NDE professionals and tools
  - Technology demonstrations
  - Warehouse space for conducting research and storing pipe samples sensitive to the elements
  - State-of-the-art meeting space with conferencing capabilities
Pull Test Strings

Liquid Test Loop

Pipe Warehouse & Testing Space
Pipe Sample Inventory at TDC

- 1,158 total pipe samples; pipe size range from 2” to 52”
Facility - Pull-Test Winch
- High capacity (up to 40,000 lbf pulling force, 18,143 kgf)
- Software controlled (automatic run and speed control)
- Speed range 0.5 to 11 mph (0.2 to 5 m/s)
Example of Unity Plots (Metal Loss Length)

Artificial ML features

Natural ML features

In line with other comparison experiences in the industry.
EmatScan
Crack Detection
most accurate crack detection
(gas)
EmatScan™ CD – Tool Overview

- Optimum sensor spacing for crosstalk avoidance
- High detection redundancy features detected 5 – 7 times => malfunction of a sensor not causing specification degradation
- Doubled amount of detection sensor compared to 1st GEN tool additional feature type discrimination sensor
- 6 independent sensor carriers electronic, data acquisition, pendulum
EmatScan™ CD – Wave Types

- Lamination
- Crack
“RH waves”: Rayleigh waves for intern/extern discrimination

“SH waves”: Horizontal shear waves for crack detection

“Lamb Wave”: Feature Type Discrimination
EmatScan™ CD

coupling free crack detection in gas pipelines

absolute depth sizing

screening for features which would fail hydrotest

securing POI performance by new discrimination sensor

mechanical damage

IPC2014-33451
IPC2016-64216
AXISS™
ILI AXIAL Strain Measurement
轴向应变检测
ILI based Axial Strain Technology 轴向应变内检测技术

- First inline inspection for axial strain in 2010 第一次轴向应变内检测在2010年
- Applied strain sensor technology used in other industries to pipelines 应变传感器技术在其他工业领域早有应用
- Complete picture of the strain threats to a pipeline when coupled with bending strain 与弯曲应变结合可以得到管道的完整应变状态
- Not site specific 并非特定于站点
- Proactively identifies areas subject to significant strain before they become injurious to the pipeline. 主动探测严重应变区域在它们对管道变成有害前
- Absolute strain values can be provided that can now be used in fitness for service decisions 绝对应变值可以由于适应性评价
Thank You