Advances in Comprehensive Integrity Assessment of Buried Pipelines with Non-Contact Magnetic Gradient Tomography Method (MTM-G).

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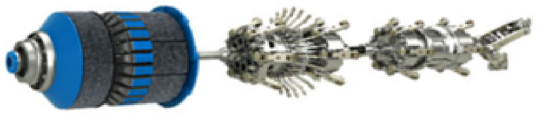
Presentation Outline

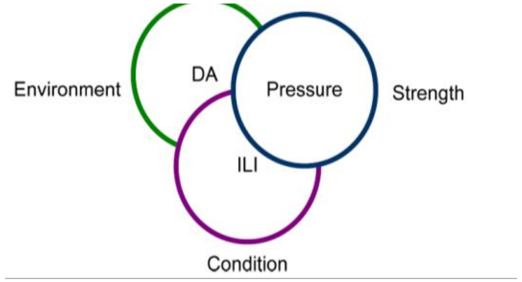
- Introduction
- MTM-G & Pipeline Integrity Improvements
- Applications
- Conclusions

Pipeline Integrity Assessment Techniques

- Hydrostatic Pressure Testing
  - Intrusive, destructive and non-predictive
- Inline Inspection (ILI)
  - Intrusive, non-destructive, reactive



- **Direct Assessment**
  - Non-intrusive, non-destructive, predictive



- There are pros and cons of each technique but whenever possible, combining two inspection techniques is an effective way of managing pipeline integrity

Comparison of Pipeline Integrity Assessment Methods			
Description	Inline Inspection	Direct Assessment	Hydrostatic Testing
Methodology	Reactive, intrusive and non-destructive. Uses low to high resolution inspection tools for determining pipe wall metal loss with location and size of defects	Proactive, non-intrusive and non-destructive. Involves a four-step iterative approach including pre-assessment, indirect inspection, direct examination and post-assessment	Intrusive, and destructive. Involves filling the pipe with water and raising the pressure above normal operating range to check for leaks and ruptures
Assessment of Output	Provides full coverage of pipe wall, reports defect size for those anomalies above the tool detection threshold	Proactive and provides susceptible defect status but full coverage may be limited by right-of-way condition (ROW) and other factors	Provides full coverage with no quantitative defect data. Only defects that fail at the hydrostatic test pressure are identified; no information regarding the presence of sub-critical defects is provided
Pipeline Integrity Status / Deliverables	Provides a clear indication of the defects on the pipe wall with locations and sizing at the time of inspection	Since the pipe is exposed during direct examination stage of the process, it can provide a quantitative and qualitative status of the pipeline's general condition including susceptible defect data sizing and location with direct examination and validation	A Pass/Fail test that provides a general confirmation that the pipe is able to operate above the designed pressure with no quantitative defect data. Cannot be used for corrosion growth analysis

C. Onuoha et al, C2017-9648 NACE 2017

Comparison of Pipeline Integrity Assessment Methods			
Description	Inline Inspection	Direct Assessment	Hydrostatic Testing
Limitations	Reactive; defects have to occur and be above the tool detection threshold to be reported. As an intrusive inspection technique, pipeline modifications and downtime including the risk of the tool getting stuck are drawbacks	ROW condition, coating type, depth of cover and other factors can preclude ECDA. Being a non-intrusive inspection technique, it does not require shutdown or any special preparation but data collection, integration and analysis could be challenging and intensive	Destructive and downtime is mandatory. Disposal of hydrotest water can be an environmental concern and water can promote internal corrosion if not properly treated. Cannot be used for corrosion growth analysis. Pass/Fail test that only gives information on the condition of the pipe at the time of the inspection

C. Onuoha et al, C2017-9648 NACE 2017

Comparison of Pipeline Integrity Assessment Methods

Description	Inline Inspection	Direct Assessment	Hydrostatic Testing

Cost Comparison of the Three Approved Inspection Techniques (Source: Appendix E, Gas Liquid and Transmission Pipelines, Neil G. Thompson, Ph.D.)

Inspection Method	Total Cost of Preparing all Pipelines in USA		Total Cost of Inspecting all Pipelines		Total	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
	($*billion)		($*billion)		($*billion)	
ILI	9.72	32.57	1.58	2.41	11.3	34.98
Hydrostatic Testing	0.54	2.17	6.67	20.20	7.21	22.37
Direct Assessment	0	0	1.09	3.69	1.09	3.69

- Shows the total cost of lost production and illustrates the cost of preparing a pipeline for an inspection method and the cost of the inspection itself.
- This shows that a robust but reliable DA methodology is extremely important in terms of avoiding business interruptions caused using some ILI tools

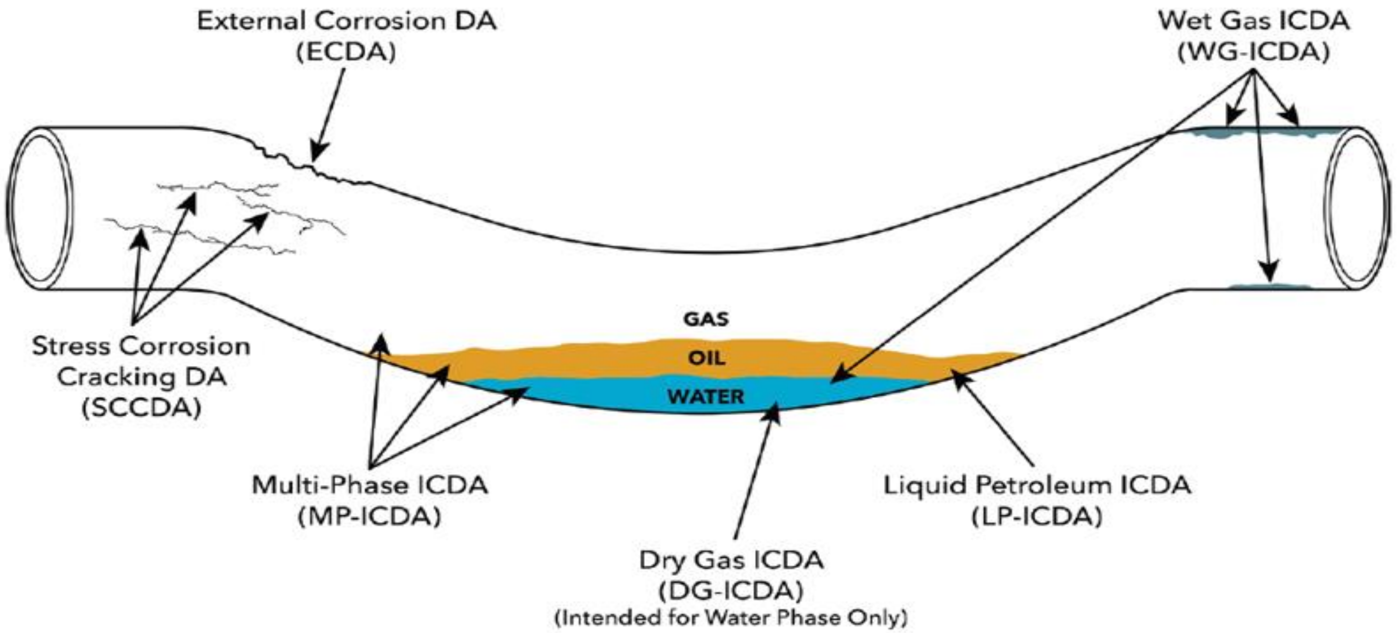
Direct Assessment (DA)

- DA methodologies can be used to detect pipeline time-dependent threats
  - External Corrosion Direct Assessment (ECDA)
  - Stress Corrosion Cracking Direct Assessment (SCCDA)
  - Internal Corrosion Direct Assessment (ICDA)
- DA process can be applied to both piggable and difficult to pig pipelines
- DA involved systematic and thorough four step processes

Direct Assessment (DA) Steps

- **Step 1**: Pre-Assessment
  - Data gathering and integrating corrosion threat factors
- **Step 2**: Indirect Inspection
  - Identify suspected areas of corrosion
- **Step 3**: Direct / Detailed Examination
  - Confirm corrosion sites (most probable locations)
- **Step 4**: Post Assessment
  - Evaluation

Most Probable Locations (MPL) vs DA



DA Methods and Their Spatial Relationship showing most probable locations along the pipeline (NACE DA Course)

External Corrosion-Buried Onshore Pipelines

External Corrosion Direct Assessment on Buried Onshore Oil & Gas Pipelines; ECDA (AMPP SP0502-2010)

- Evaluation of external corrosion likelihood on buried onshore coated and cathodically protected pipelines relies on ascertaining the level of cathodic protection, coating condition and soil corrosivity.

- Basis is that in an ideal condition, locations that have adequate cathodic protection per AMPP SP0169-2013 should have low likelihood of external corrosion.
  - Locations with inadequate CP with coating anomalies, and in highly corrosive soils should have the highest likelihood of external corrosion.

External Corrosion-Buried Onshore Pipelines

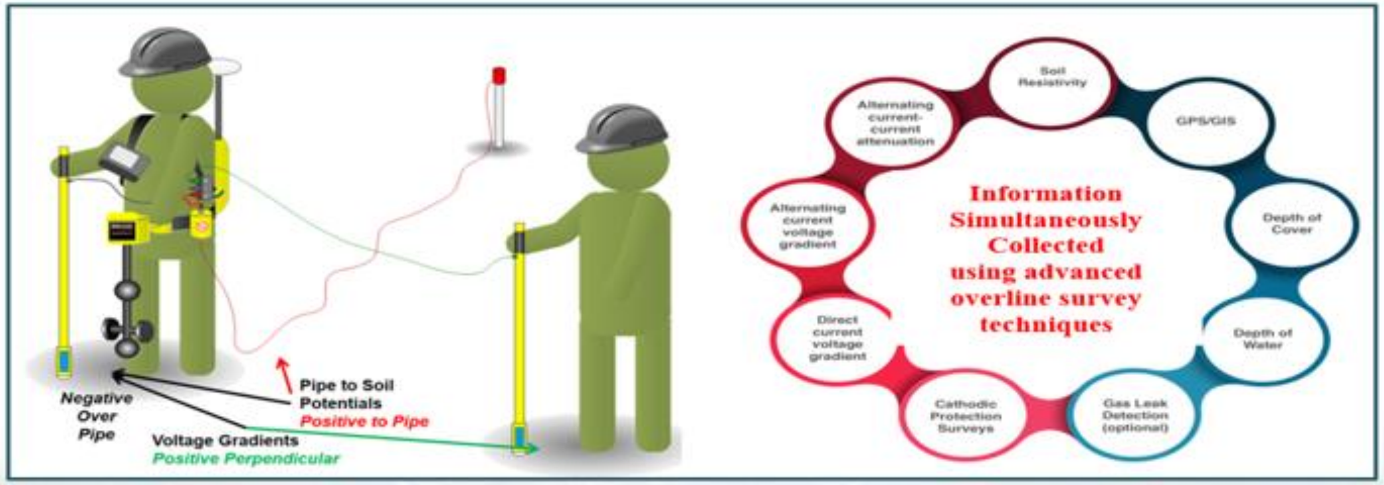
- Screen and complete the pre-assessment to determine whether ECDA is the appropriate integrity assessment method for the selected pipeline segment.
  - Requires detailed evaluation of likelihood of external corrosion that may have been present in the pipeline during history.
  - Detailed information required for the pre-assessment is document in Table 1 of NACE SP0502-2010.

Screen for ECDA	
Category	Screening Factors
Indirect inspection to assess the external corrosion likelihood cannot be successful completed (interference currents, obstructions on right of way, depth of cover, presence of rock and rock ledges, pipeline with newly applied highly dielectric shielding coatings, other factors that prohibit indirect inspection)	No
The pipeline cannot be made accessible for direct examinations	No

NACE is now AMPP

External Corrosion-Buried Onshore Pipelines

- Conduct the indirect inspection to assess the external corrosion likelihood
  - CP CIPS to identify areas of inadequate cathodic protection per NACE SP0169-2013
  - ACVG, DCVG, ACCA to identify coating anomalies
  - Soil resistivity to assess soil corrosivity



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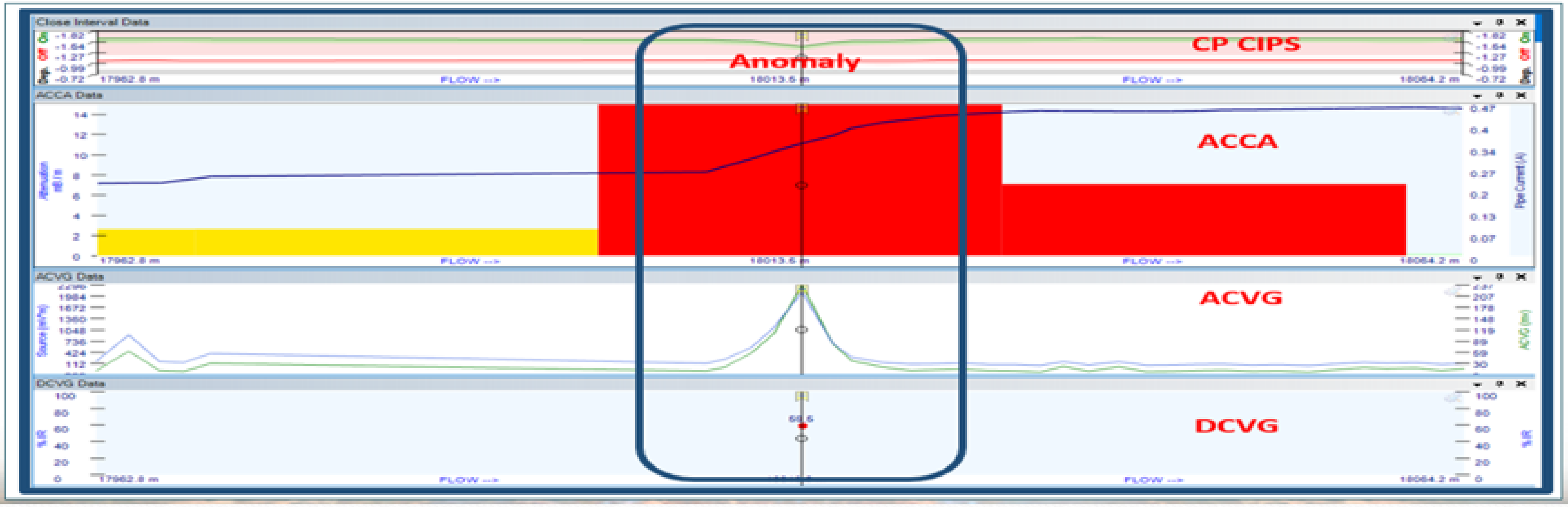
AMPP Calgary, 2021

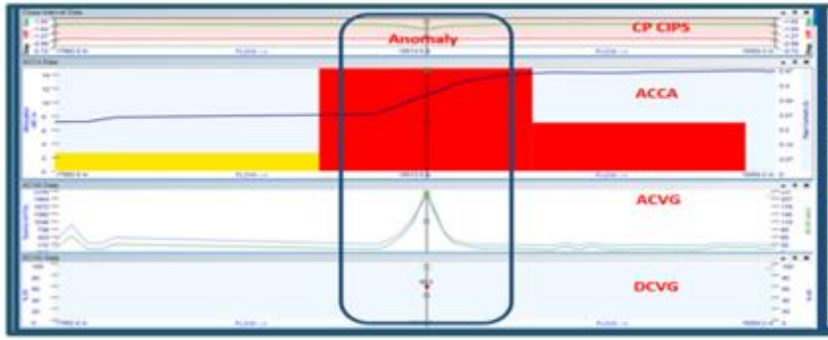
External Corrosion-Buried Onshore Pipelines

- Identification and alignment of indications
  - Coating anomaly areas, locations with insufficient CP, highly corrosive soils
  - Correlation of aboveground indications with reported ILI external metal loss (if piggable)



External Corrosion-Buried Onshore Pipelines

- Complete the direct examination on identified sites most likely to experience external corrosion
  - Classification and prioritization of indications
    - Refine the Severe, Moderate , Low risk indications
    - Develop risk matrix to select direct examination locations and / or follow-up investigations



- Complete the post-assessment to assess the effectiveness of the program and to determine the reassessment intervals.

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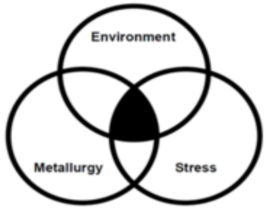
Stress Corrosion Cracking-Buried Onshore Pipelines

Stress Corrosion Cracking Direct Assessment on Buried Onshore Oil & Gas Pipelines (natural gas, crude oil, refined products); SCCDA (AMPP SP0204-2015)

- Evaluation of stress corrosion cracking likelihood on onshore coated and cathodically protected pipelines relies on the previous history of SCC, operating stress level, distance from compressor / pump station, operating temperature (for high-pH SCC), age of the pipeline and coating type.
- For SCC to occur, the susceptible buried pipeline **must** be exposed to environments conducive to stress corrosion cracking.



Conditions for SCC

Stress Corrosion Cracking-Buried Onshore Pipelines

- Screen and complete the pre-assessment to determine whether SCCDA is the appropriate integrity assessment method for the selected pipeline segment.
  - Requires detailed evaluation of stress corrosion cracking likelihood that may have been present in the pipeline during history.
  - Detailed information required for the pre-assessment is document in Table 1 of NACE SP0204-2015.

Screen for SCCDA

Category	Screening Factors
Previous SCC history	No
Operating stress level > 60% SMYS	No
Age of pipeline > 10 years	No
Coating type is plant applied, or field applied FBE or liquid epoxy	No
Operating temperature > 38°C (100°F) for high-pH SCC	No
Distance from downstream compressor (Gas pipeline) or pump station (liquid pipeline) is < 32 km (20 miles) mostly for high-pH SCC	No

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Stress Corrosion Cracking-Buried Onshore Pipelines

- Gather additional data during indirect inspection to support prediction of SCC locations
  - CP CIPS to identify areas of inadequate cathodic protection per NACE SP0169-2013
  - ACVG, DCVG, ACCA to identify coating anomalies
  - LSM to identify areas of stress concentrations
  - Soil resistivity, pH and terrain surveys to identify and integrate environmental and pipe characteristics to further delineate susceptible areas

- Identification of SCC indications from aboveground
  - Coating anomaly areas, locations with insufficient CP, stress concentrations

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Stress Corrosion Cracking-Buried Onshore Pipelines

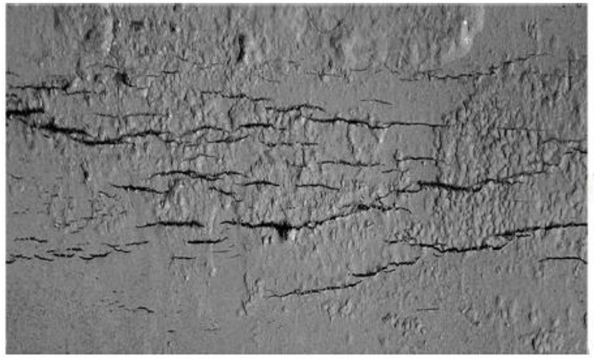
- Correlation of aboveground SCC indications with reported ILI indications (if piggable)
  - Reported external metal loss, dents and / or areas of coating disbondment on segments that are coated with high dielectric coatings that shields under disbondment
- Complete the direct examination on identified sites most likely to experience stress corrosion cracking
  - Classification and prioritization of SCC indications
    - Refine the Severe, Moderate , Low risk indications
    - Develop risk matrix to select direct examination locations and / or follow-up investigations
- Complete the post-assessment to assess the effectiveness of the program and to determine the reassessment intervals.

Non-Contact Magnetic Gradient Tomography Method (MTM-G)

Some reasons of pipeline failure

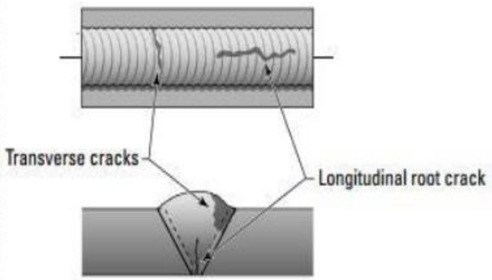
CORROSION

- Internal
- External
- Etc.



CRACKING

- Material property
- Operating conditions
- Etc.



WELD FAILURE

- Cracking
- Overheating
- Etc.

EXTERNAL FORCES

- Natural forces
- Operating conditions
- 3rd Party damage

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GENERAL INSPECTION METHODS

BY ACCESS TYPE TO THE PIPELINE

INTERNAL

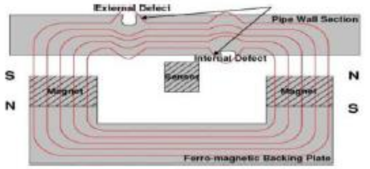
- Pigs
- Robotics

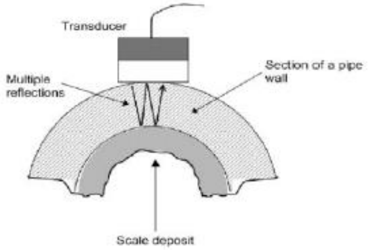
EXTERNAL

- Contact based tools
- Crawlers

BY TYPE OF TECHNIQUES:

- MFL
- Ultrasonic
- TFI
- Eddy current
- Geometry
- Sonar
- etc





LIMITATIONS OF CURRENT METHODS

- Mandatory internal or external contact
- Isolation of pipeline / stop service
- Pipeline preparation (cleaning etc.)
- Require launchers and receivers for pigs or crawlers
- Pipelines which cannot be pigged and cannot use internal crawlers
- Pipelines which cannot be isolated are buried and unpiggable
- Anomalies which are not within the detectable range but are critical

NO SOLUTIONS IS 100%

CURRENT INTEGRITY ASSESSMENT APPROACH

- According to ASME B31G, DNV-RP-F101, API codes, the failure of corroded pipelines is controlled by the defect size as well as the flow stress of the material
- Defect sizing is important but sometimes is not enough for assessing the integrity
- Codes refer to the **mechanical stresses** as a key factor
- All conventional techniques like as ILI are based on the defect sizing (dents, corrosion, cracks) showing the limits and not entire picture of integrity…

HOW TO EVALUATE WHICH ANOMALY IS MORE CRITICAL ?

STRESS

Non-Contact MTM-G

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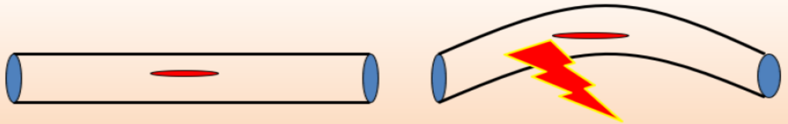
How to understand "stress"? What does this term mean ?

- Example 1. Defects of the same size and type allocated on the same pipeline. One sample is under external loads (i.e. pressure, bending, temperature, etc)

Q. Which will most likely fail first?

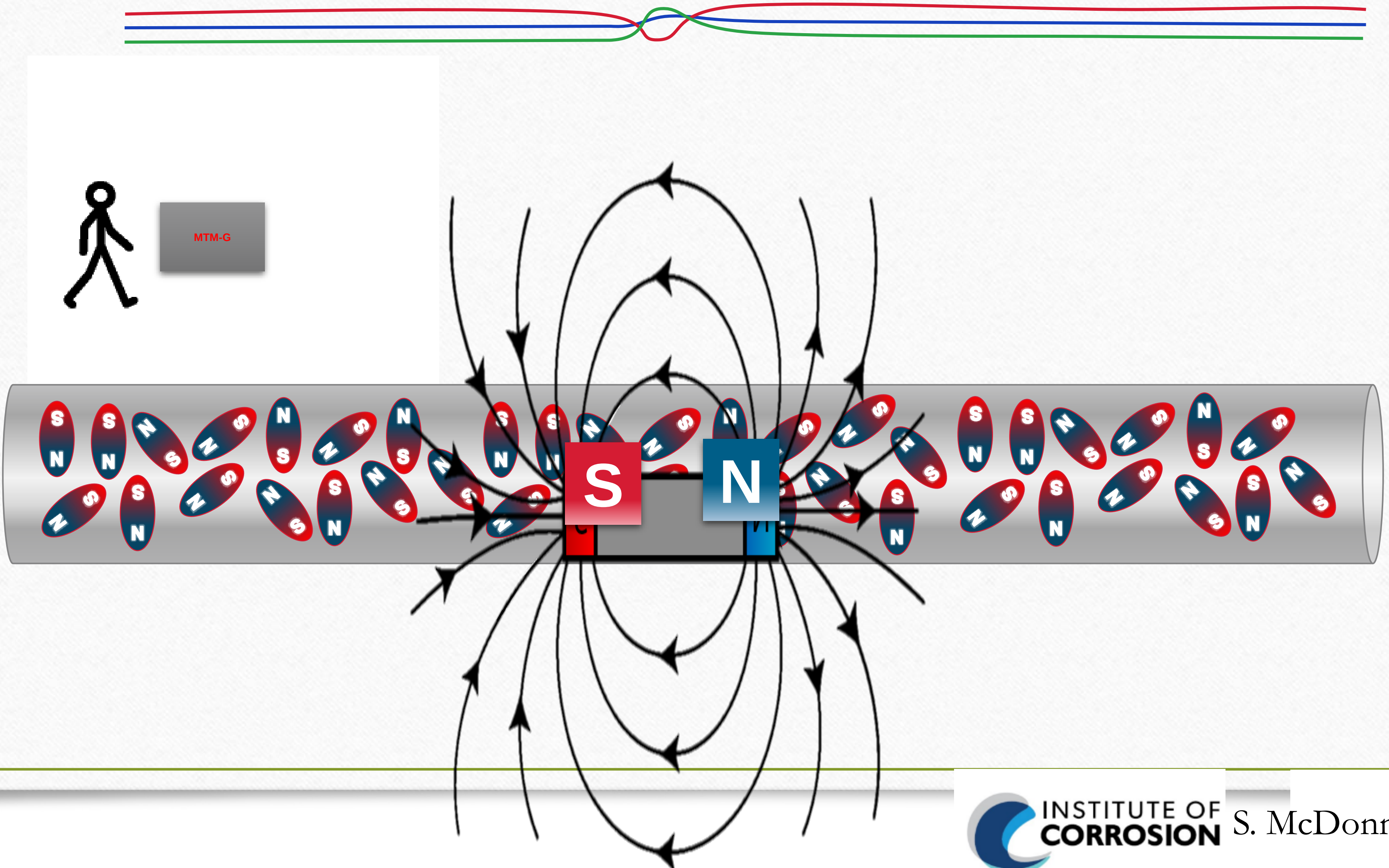
DEFECTS OF THE SAME SIZE AND TYPE
Which will most likely fail first?



THE GEOMETRIC SIZE OF EACH ANOMALY ALONE, CANNOT DETERMINE THE PIPELINE'S INTEGRITY

Very important to identify the stress at each anomaly or pipeline segment to evaluate which is more critical

IGSAT Integrity Global Satellite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Non-Contact MTM-G

- MTM-G; other industry trade names; SCT, PWA and LSM
- Pipeline locating, GPS mapping and field inspection are integrated in the same survey
- Can be applied in both onshore and offshore pipelines
- On onshore pipelines, depth of cover must be less than 7m to ensure confidence in probability of detection
- Technicians walk with magnetic sensor on the pipeline right-of-way of subject pipeline capturing areas of stress concentrations (elevated stress levels)
- After field inspection, data is processed and analyzed in proprietary software where all captured anomalies are classified and prioritized.
- All classified and prioritized anomalies have GPS coordinates and aboveground markers (AGM) for reference

Non-Contact MTM-G

- Pipeline defects occurring during fabrication are usually identified before burial and verified against industry set standards. However, with time some pipelines will invariably develop stress concentration zones due to internal or external forces leading to pipeline failure; stress failures are most commonly due to cracks, dents, buckles, etc. If these indications are identified proactively, it will improve safety and significantly save cost in downtime

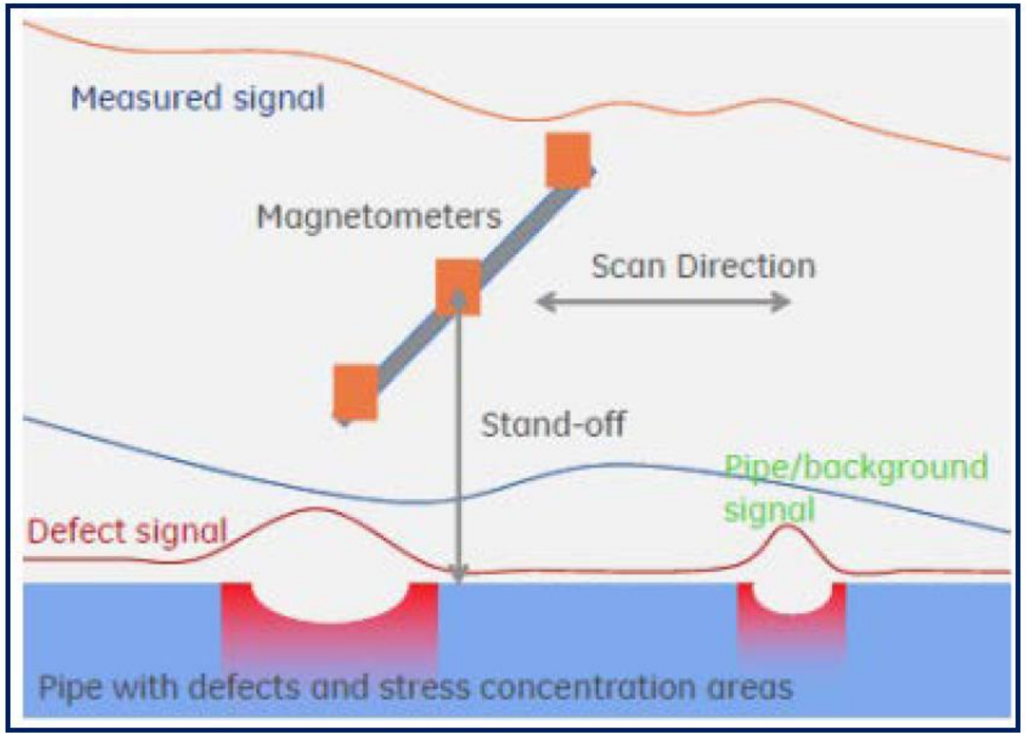
- Non-Contact Magnetic Gradient Tomography Method (MTM-G) is a non-destructive testing (NDT) technology used for detecting anomalies and evaluating the integrity of pipelines. This method can be applied to inspect pipelines located above ground, underground, and offshore, irrespective of their type and size.

Non-Contact MTM-G

- MTM-G is used to identify and locate elevated levels of stress through the measurement of the magnetic field surrounding steel pipelines, regardless of the ability to pig or whether the pipeline is buried, exposed, or elevated.

- A change in magnetic field could indicate the presence of stress in the pipe wall. The shape change of a ferromagnetic material during magnetization is characterized as magnetostriction. Inverse magnetostriction, known as the Villari effect, characterizes the change of magnetization when mechanical stresses are applied to the material. This change in magnetization due to mechanical stress is what **the MTM-G can detect.**

Non-Contact MTM-G



Onuoha et al, AMPP C2020-14475

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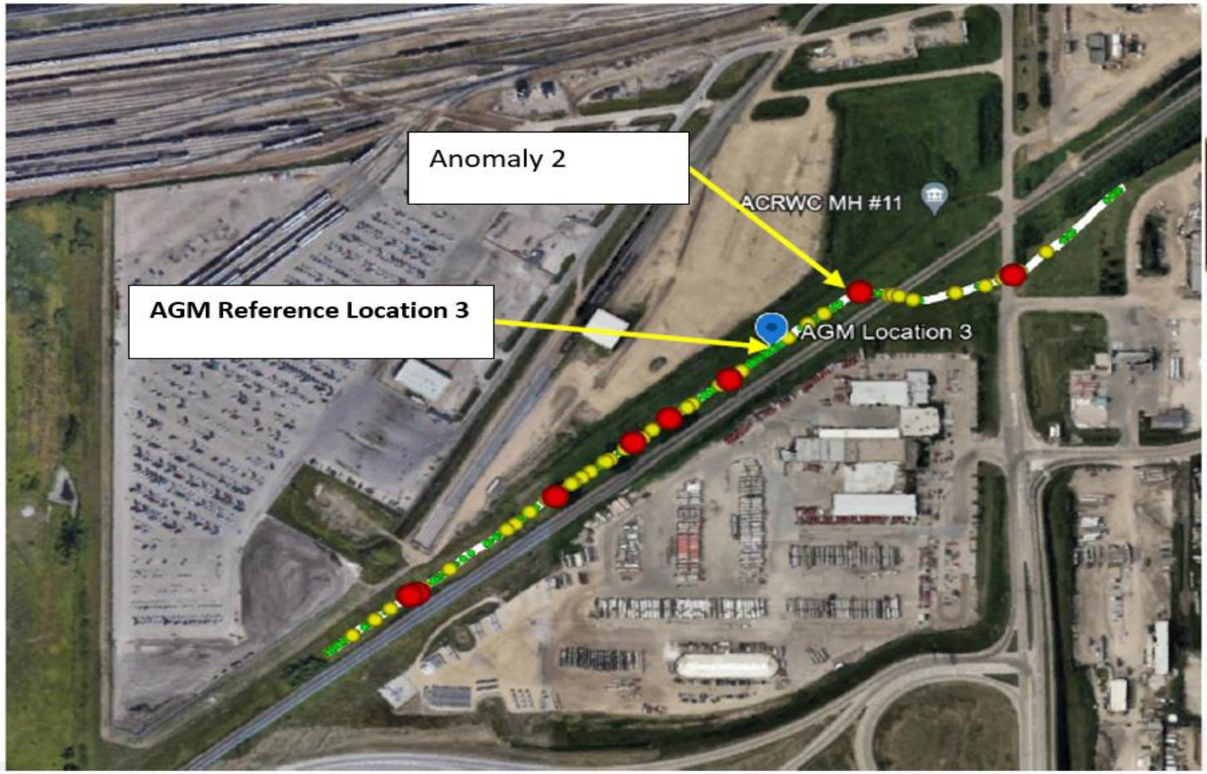
ANOMALIES RANKING BY TYPES

Crack-like defects	Guide marks, blisters, laps, SCC defects, etc.
Metal loss (*)	Local character (comparatively to the outer pipeline diameter) of the hoopstress change associated with the corrosion or non-corrosion type of the flaws, i.e.: - localized form of corrosion by which cavities or "holes" are produced inthe material, - metal loss due to the local corrosion damage. - local nominal wall thickness change - etc.
Weld anomaly	Pores, lack of fusion, cracks, edge displacement, cuttings inside of theweld or close heat-affected zones (HAZ) area
Geometry changes	Compression marks, corrugations, ovality, corrugated pipe, mechanicaldamages - dents, scores, etc.
Metal loss (**)	Distributed character of the hoop stress changes not necessary limiting bythe outer pipeline diameter associated with the corrosion or non-corrosiontype of the flaws, i.e.: - Erosion corrosion and selective leaching - Nominal wall thickness change due to different type of spools - etc.
Stress-deformed condition	Sections with deviations in general stress-deformed conditions caused bysaggings, free-spannin, bending, longitudinal, circumferencial or twisting loadings in land sliding, soil erosion, soil movements etc.
Discontinuity	Laminations, non-metalic inclusions, bubbles, swellings under theinfluence of hydrogenating media within the process of operation

MTM-G & Pipeline Integrity Improvements

- **Identification of pipeline anomalies**
- **Characterization**
- **Prioritization**

- **DA & MTM-G can be combined to help identify and characterize anomalies before pipeline excavation**
- **CP, DCVG, ACVG, ACCA, Soil & MTM-G**



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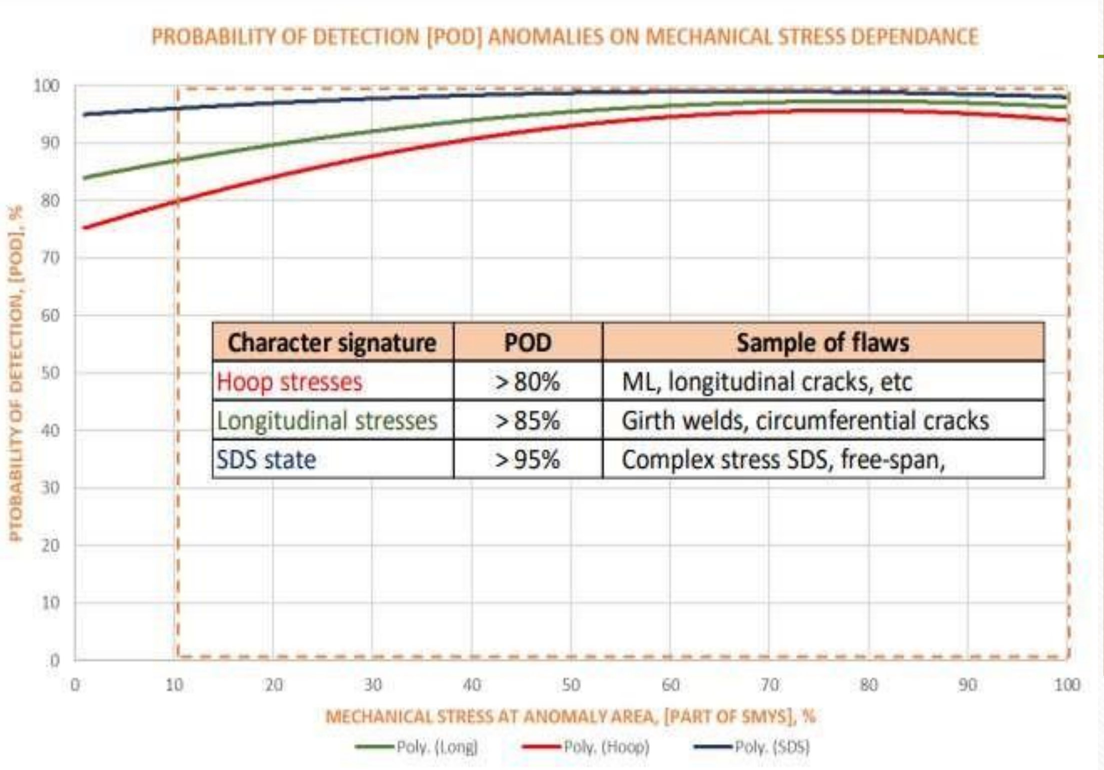
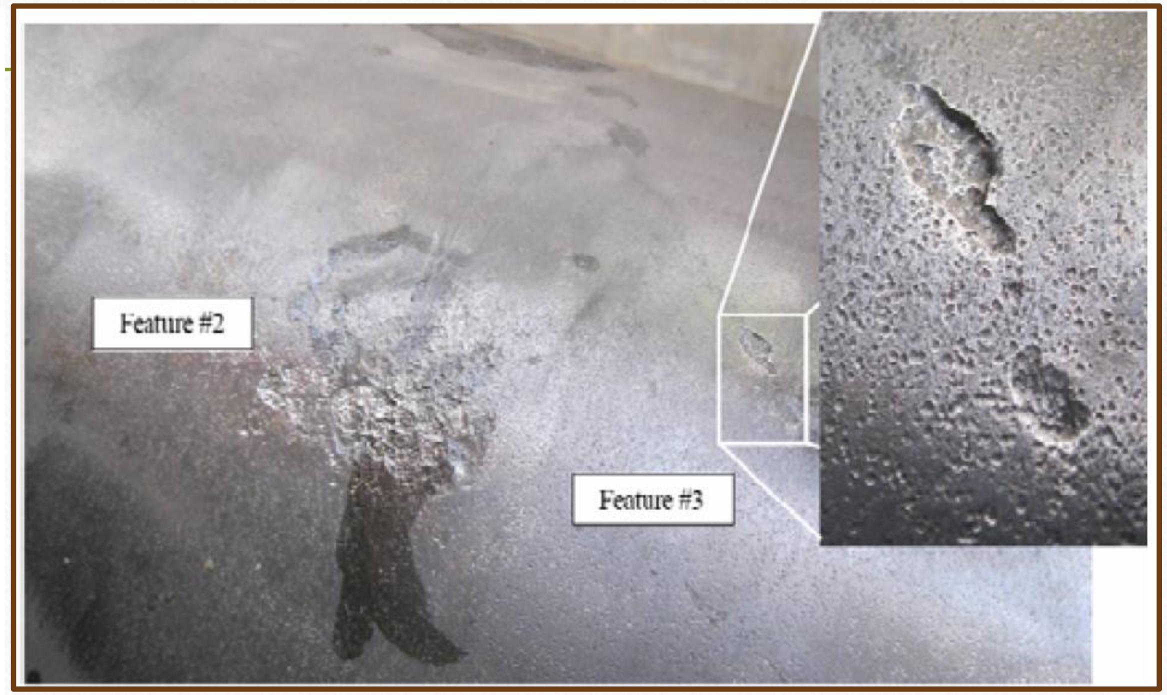
Identification of Anomalies



Character signature	POD	Sample of flaws
Hoop stresses	> 80%	ML, longitudinal cracks, etc
Longitudinal stresses	> 85%	Girth welds, circumferential cracks
SDS state	> 95%	Complex stress SDS, free-span,



External Metal Loss Reported by MTM-G & Validated

Characterization of Anomalies

Anomaly distribution by types:

Gr. 1 – Crack like anomaly
Gr. 2 – Metal loss, Local
Gr. 3 – Weld anomaly
Gr. 4 – Geometry change
Gr. 5 – General SDS
Gr. 6 – Metal loss, General
Gr. 7 – Inside wall flaw (Inclusions, Lamination, Delamination)

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Prioritization of Anomalies

Integrity log summary

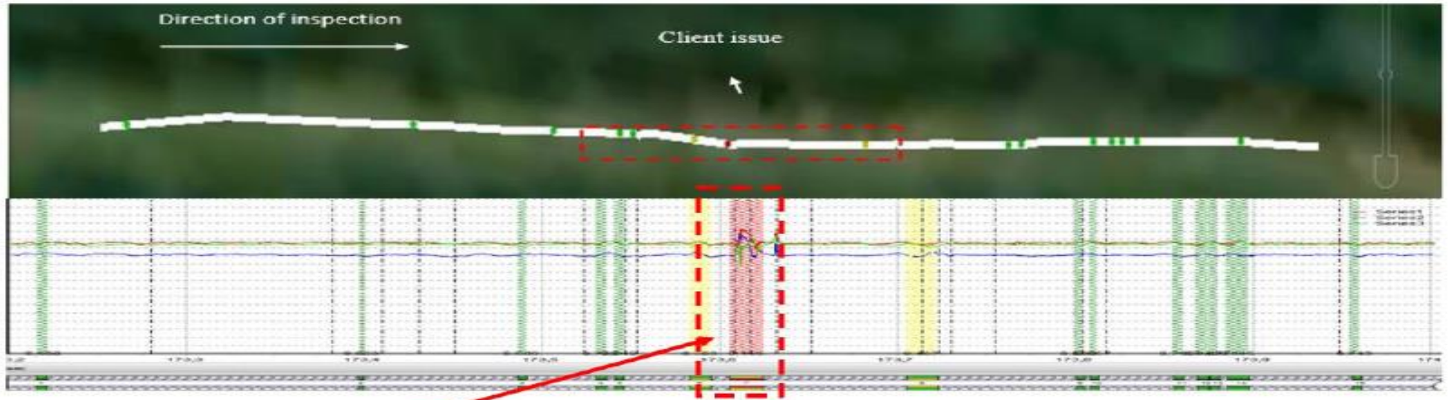
№ anomaly	Metal State	Information about anomalies							Risk Factor F	KP start [m]	KP end [m]	Length,m	Calculated Safe Operation Term		Stress Concentration Factor, SCF	PSAFE, [MPa]	Estimated Repair Factor, ERF	Nominal WT, mm	Hoop stress equivalent
		Stress signature						Discontinuity/ Lamination					P=Psafe	P=MOP					Metal loss, [% of WT]
		Crack-flaw indication	Metal loss (* local character)	Weld anomaly	Geometry changes	Stress-deformed state	Metal loss (* general character)												
1	3	+	-	+	+	+	+	-	0,629	9,8	12,0	2,2	17	42	1,354	8,739	0,114	12,7	<20
2	2	-	-	-	-	+	-	-	0,375	15,4	16,8	1,4	8	18	1,805	6,555	0,153	12,7	-
3	2	+	+	+	+	+	+	-	0,255	19,5	23,2	3,6	5	11	1,895	6,242	0,160	12,7	27
4	3	-	-	+	-	-	-	-	0,936	48,8	50,5	1,8	49	122	1,039	11,383	0,088	12,7	-
5	3	+	-	+	+	+	+	-	0,575	64,8	65,6	0,8	15	35	1,521	7,776	0,129	12,7	<20
6	3	+	-	+	+	+	+	-	0,733	68,4	69,1	0,7	23	56	1,300	9,100	0,110	12,7	<20
7	3	-	-	-	-	+	-	-	0,822	69,9	70,5	0,6	30	75	1,187	9,964	0,100	12,7	-
8	3	-	-	+	-	+	-	-	0,952	77,9	79,3	1,4	53	133	1,029	11,499	0,087	12,7	-
9	3	-	-	+	-	-	+	-	0,839	85,0	86,3	1,3	32	80	1,137	10,407	0,096	12,7	<20
10	2	-	-	+	-	+	+	-	0,458	89,9	91,7	1,8	10	25	1,623	7,292	0,137	12,7	21
11	3	-	-	-	-	+	-	-	0,555	101,5	103,2	1,7	14	33	1,480	7,996	0,125	12,7	-
12	2	+	+	+	+	+	+	-	0,265	127,0	129,5	2,6	5	12	1,929	6,133	0,163	12,7	28
13	3	-	-	+	-	+	+	-	0,823	160,5	161,8	1,3	31	75	1,155	10,246	0,098	12,7	<20
14	3	-	-	-	-	+	-	-	0,936	241,9	243,6	1,8	49	122	1,040	11,376	0,088	12,7	-
15	3	-	-	-	-	+	-	-	0,852	276,1	276,6	0,4	34	83	1,158	10,219	0,098	12,7	-
16	3	-	-	-	-	+	-	-	0,839	289,5	291,6	2,1	32	80	1,122	10,550	0,095	12,7	-
17	2	-	-	+	-	+	+	-	0,366	323,1	325,9	2,8	8	18	1,716	6,896	0,145	12,7	24
18	2	-	-	+	-	+	+	-	0,421	348,7	350,6	1,8	9	22	1,680	7,044	0,142	12,7	23

Distribution by types

Integrity summary

MTM-G & Pipeline Integrity Improvements

Anomaly No. 7 : Metal-state (Weld anomaly indication) at KP 173.605



- Anomaly No. 7 has the first Rank (#1) of criticality by Metal State (Weld Anomaly indication and requires attention.

MTM Results						Based on P= Pi		Based on P=MAOP		Based on P=Psafe	
No. of anomaly	SDS	Metal State	Risk Factor F	Stress Concentration Factor, SCF	Pafe [MPa]	MTM Stress [Mpa]	MTM Strain [mm /mm]	MTM Stress [Mpa]	MTM Strain [mm /mm]	MTM Stress [Mpa]	MTM Strain [mm /mm]
7	2	1	0.149	1.934	8.127	5.326	0.000021874	506.256	0.06913	221.593	0.00091

- MTM-G can identify, classify and prioritize anomalies and able to report strain

MTM-G & Pipeline Integrity Improvements

Information about anomalies								Metal loss assessment	
№ anomaly	Metal State	Risk Factor F	KP start [m]	KP end [m]	Length,m	Stress Concentration Factor, SCF	Nominal WT, mm	Metal loss (% of WT)	Remaining wall thickness, mm
1	2	0.290	157.9	161.4	3.6	1.763	5.2	43.29	2.93
2	2	0.442	226.6	230.3	3.7	1.516	5.2	34.02	3.40
3	2	0.355	252.1	256.6	4.5	1.622	5.2	38.34	3.18
4	2	0.280	348.8	351.1	2.3	1.853	5.2	46.02	2.79
5	1	0.161	360.5	368.9	8.4	1.912	5.2	47.7	2.70
6	2	0.311	464.3	472.0	7.6	1.630	5.2	38.64	3.17
7	1	0.113	504.8	509.3	4.6	2.172	5.2	53.95	2.38
8	1	0.176	511.6	513.6	2.1	2.126	5.2	52.97	2.43
9	3	0.635	567.3	570.4	3.0	1.297	5.2	-	-
10	2	0.510	645.5	647.0	1.5	1.512	5.2	33.86	3.41

MTM-G & Pipeline Integrity Improvements

Anomaly #3 detail overview

GPS		Information about anomalies							GR. 3	GR. 6
Latitude	Longitude	№ anomaly	Metal State	Risk Factor F	KP start [m]	KP end [m]	Length,m	PFG (Predicted Feature Group)	Heat effecting (Weld anomaly)	Hoop part. Metal loss (** General character)
		3	2	0.443	37.9	41.7	3.8	Weld anomaly	0.443	0.493

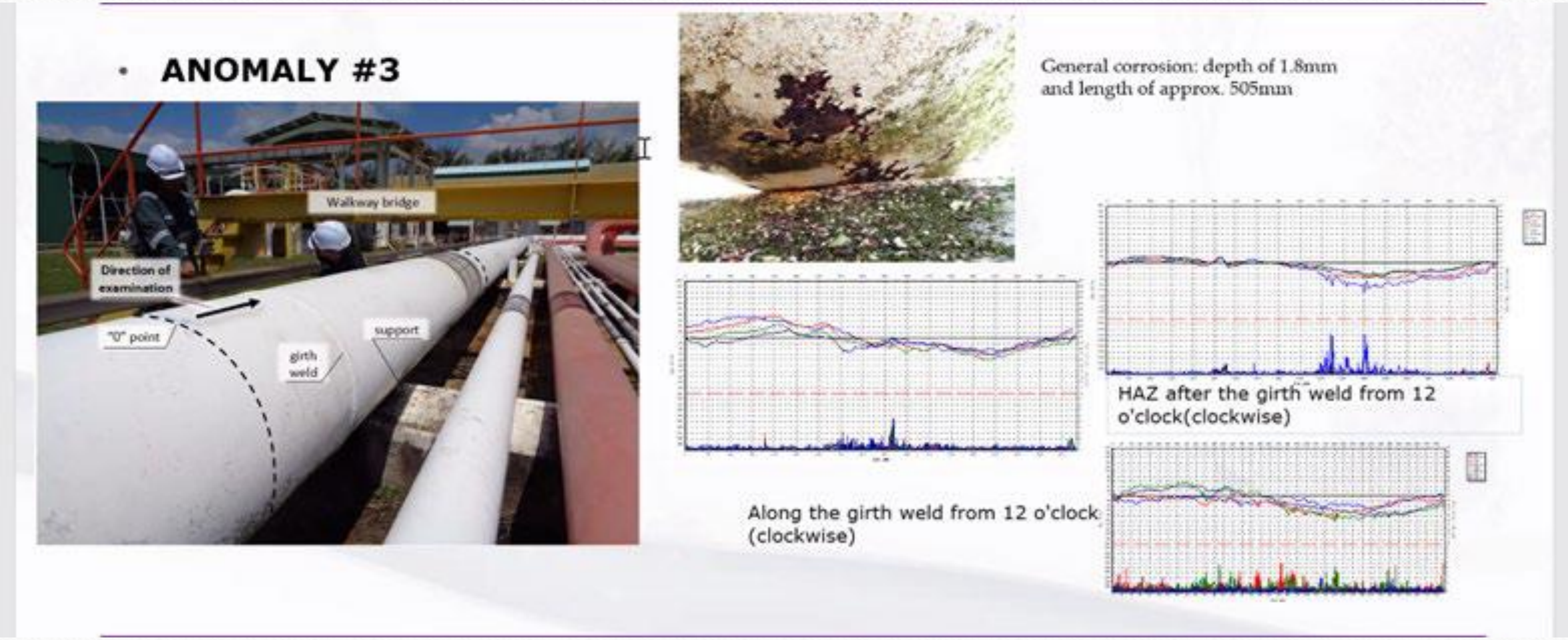
Governing anomaly

Governing anomaly, prediction feature

To be verified

Anomaly range	Category of technical condition	Risk Factor, F Range	Category of technical condition
1	INADMISSIBLE	0 – 0.2	INADMISSIBLE Section of urgent repair
2	ADMISSIBLE	0.2 – 0.55	ADMISSIBLE Section of scheduled repair
3	GOOD	0.55 – 1.0	GOOD Section can be operated without repair

MTM-G & Pipeline Integrity Improvements



Integrated MTM-G & ILI Scenario

- MTM-G offers a non-contact method for assessing pipeline integrity. It is particularly valuable in analyzing the stress state of pipelines by measuring the magnetic field gradient. This method can provide detailed insights into the types of mechanical stresses present in the pipeline, including hoop, longitudinal, and complex combinations like bending and shear stresses.

- Inline pipeline inspection tools (ILI) are well-suited for detecting physical and geometric anomalies within the pipeline, such as corrosion, metal loss, or cracks. These tools provide detailed information about the geometry and orientation of these anomalies.

Integrated MTM-G & ILI Scenario

- When ILI and MTM-G are used in tandem, they can offer a comprehensive view of the pipeline's condition. For instance, while MTM-G can directly measure the mechanical stress through the pipeline's magnetic field gradient, ILI can provide detailed information on the geometry and location of defects. This complementary data allows for a more thorough assessment of the pipeline integrity.

- This integrated approach can significantly enhance the pipeline integrity management process. The combination of MTM-G's stress assessment and ILI's detailed defect information can lead to more informed decisions regarding pipeline maintenance and operation. This synergistic method can improve the identification of potential risks and help pipeline operators to address issues more effectively.

Integrated MTM-G & ILI Scenario

- MFL Inline Inspection (ILI) is effective in detection of individual defect and measurement of sizing of each individual defect. For the pipeline integrity management program, the fitness for service assessments require to combine defects into clusters and compute the local stresses surround, and safety parameters (Psafe, MAOP, ERF, RLA) can be assessed thereafter by using known methods (ASME BG31, API, DNV etc).

- MTM-G can be effective in detection of anomalies associated with the mechanical stresses, directly measured by natural magnetic response from the pipeline material and **without necessity direct assess to the size of each individual defect**. For pipeline integrity management programs, the local stresses are registered directly and conventional safety parameters (like Psafe, Tsafe, SCF, ERF) are assessed through direct magnetic response measurements.

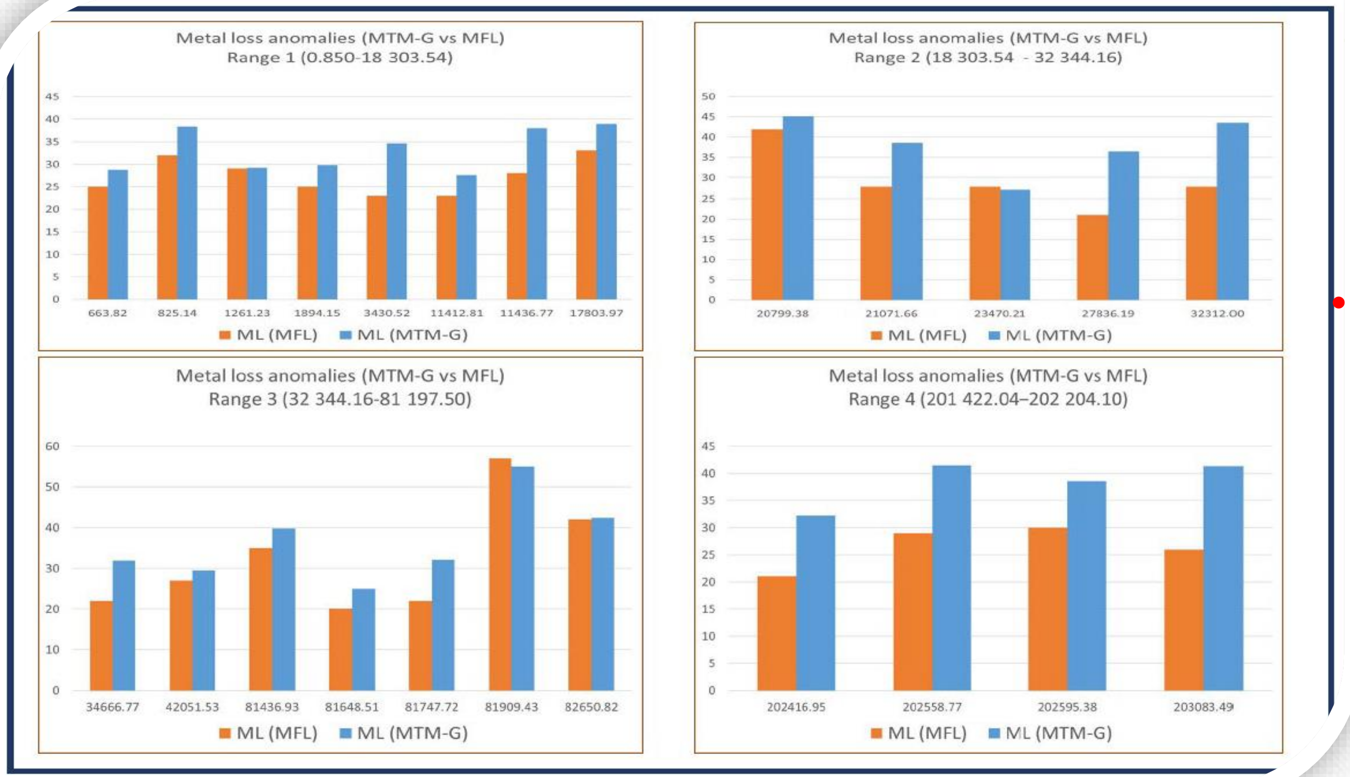
Integrated MTM-G & ILI Case Study

- This case study was conducted on 26-inch gas pipeline in-service since 1980 and inline inspection (MFL) was used to evaluate the condition of the pipeline (to confirm external corrosion depth of metal loss) and MTM-G was used on the same pipeline as a validation.

- Note that MTM-G is designed to respond to stress changes and to report stress concentration factors. It is **NOT** designed for example to measure geometrical depth of metal loss like inline inspection. The reported metal loss in the next slide is estimated from ASME B31G and proprietary algorithms.

- Based on several ILI vs MTM-G comparative inspections completed, reported metal loss estimated from measured magnetic stress from MTM-G vs actual measured metal loss from ILI is within ±10%

Integrated MTM-G & ILI Case Study



- **Ability of MTM-G to estimate external metal loss from measured stress is good news for buried unpiggable pipeline operators looking for ways to implement proactive pipeline integrity best practices**

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Conclusions

- Results from real-life case studies using MTM-G have shown strong capabilities in the identification and characterization of external metal loss and cracks and when combined with other tools, helps to prioritize areas of concern.
- Based on preliminary findings, the ability to detect corrosion metal loss and external corrosion cracks from aboveground suggests that this technology will improve pipeline integrity assessments and give more confidence to pipeline operators looking for more efficient ways to assess their unpiggable pipeline assets.
- On critical buried pipeline that demands urgent attention, an integrated approach that combines ILI and MTM-G can significantly enhance the pipeline integrity management process. The combination of MTM-G's stress assessment and ILI's detailed defect information can lead to more informed decisions regarding pipeline maintenance and operation. This synergistic method can improve the identification of potential risks and help pipeline operators to address issues more effectively.

Thank You!

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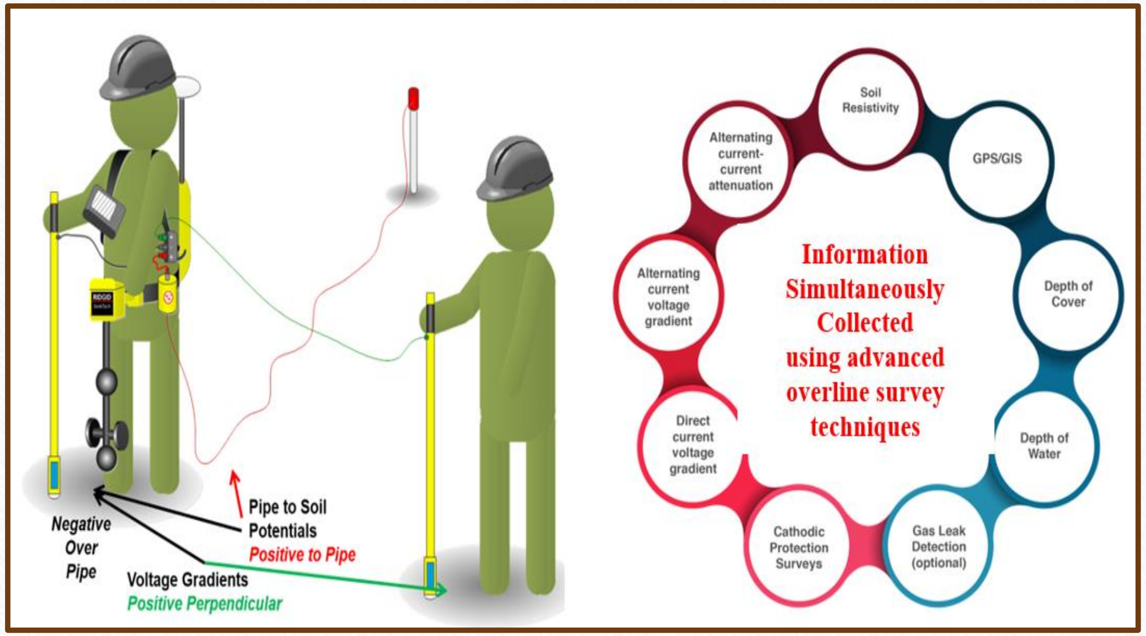
Back-up Reference Slides

Included for Information

Non-Contact MTM-G

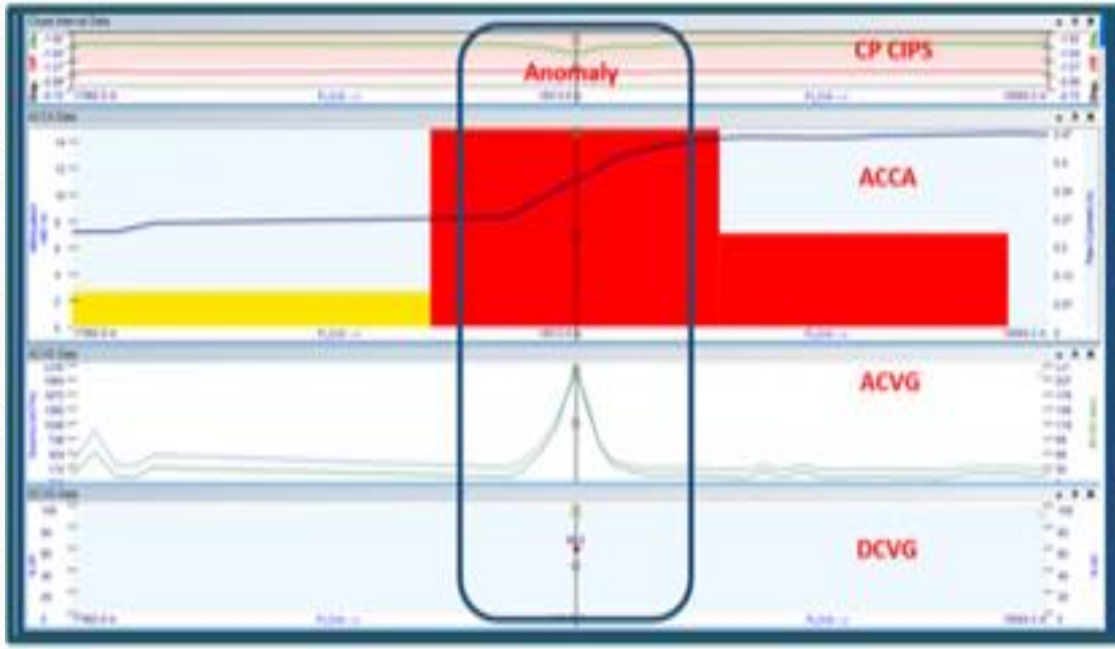
MTM-G & Pipeline Integrity Improvements



AMPP Calgary, 2021

DA & MTM-G combined can help identify and characterize anomalies before pipeline excavation

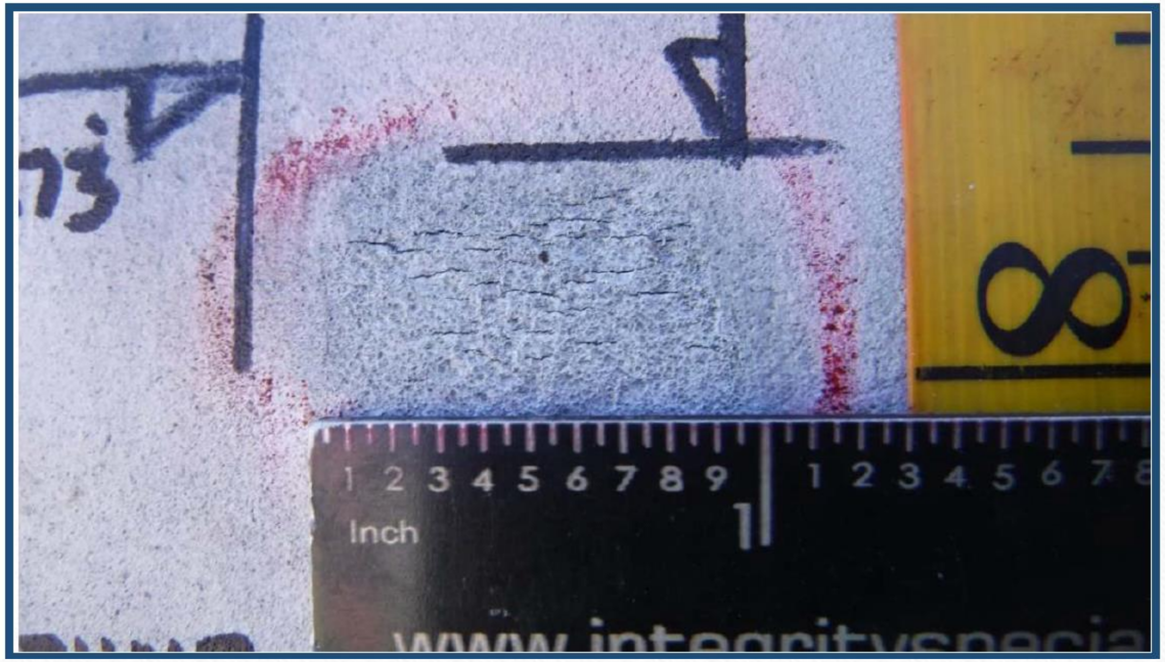
MTM-G & Pipeline Integrity Improvements



AMPP Calgary, 2021

- Robust DA tools can predict the outcome before direct examination
- With MTM-G, anomalies are further characterized before direct examination

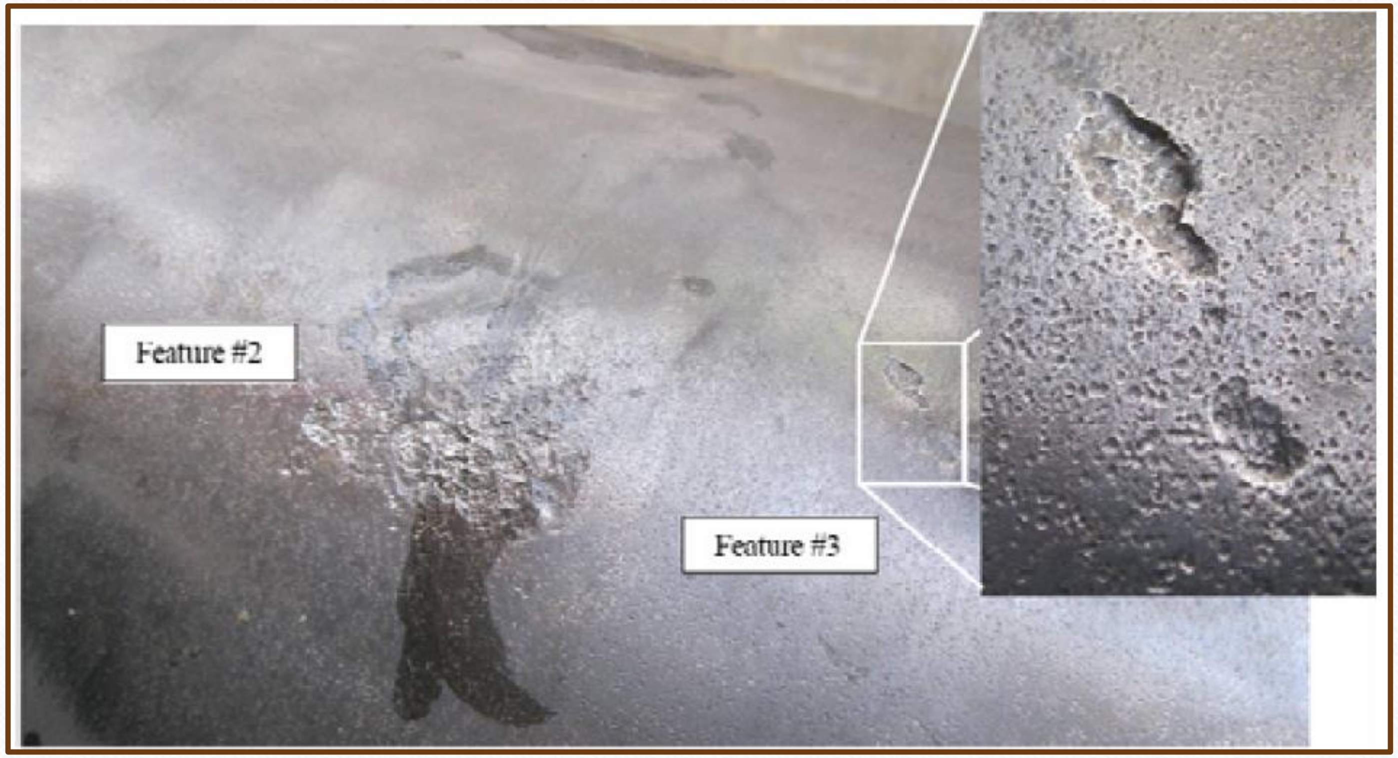
MTM-G & Pipeline Integrity Improvements



AMPP Calgary, 2021

- Robust DA tools can predict the outcome before direct examination
- With MTM-G, anomalies are further characterized before direct examination

Example of Metal Loss Reported by MTM-G & Confirmed



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MAGNETIC GRADIENT TOMOGRAPHY METHOD (MTM-G) OF PIPELINE INSPECTION

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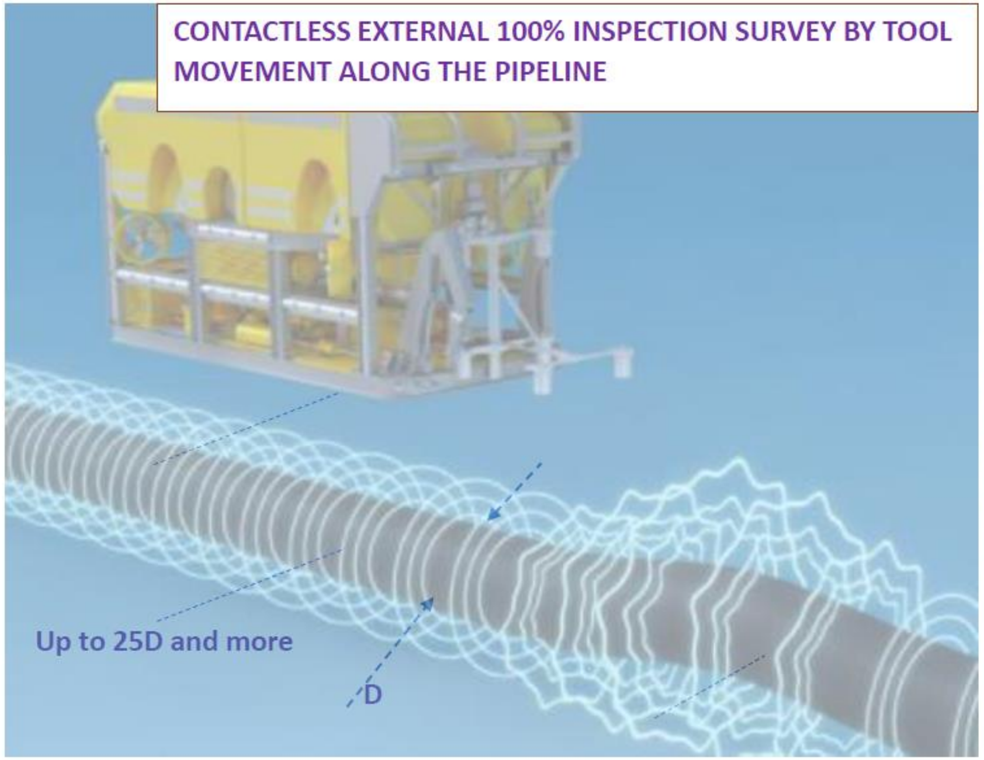
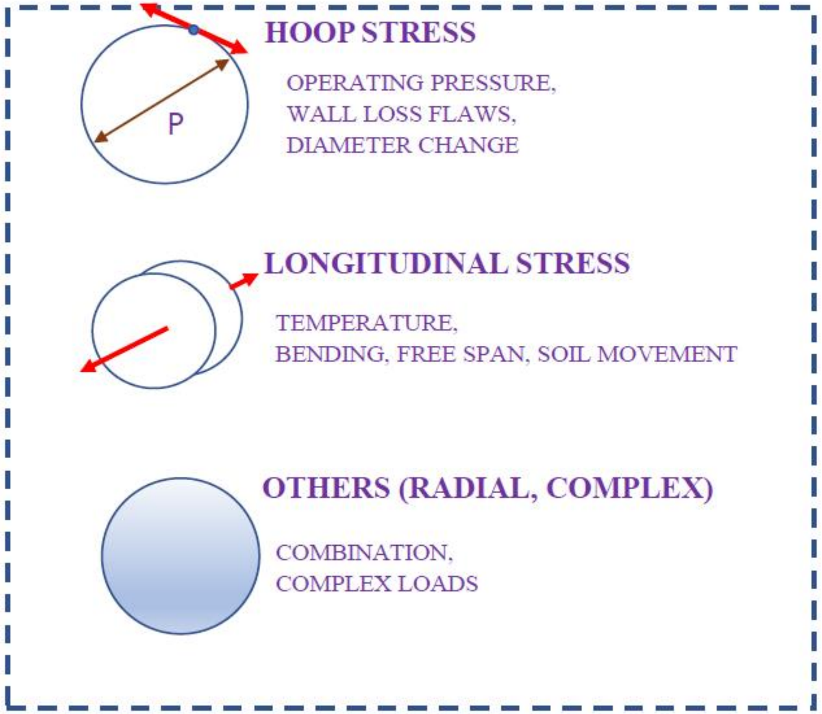
MTM-G survey assesses the integrity of the pipeline under normal operating conditions (flow, pressure, temperature) from the external of the pipeline. Survey is a continuous scanning process of magnetic field remotely along the pipeline by precision gradiometer with the allowable stand-off distance off the pipeline axis up to, potentially, 25 times of the pipeline diameter.



DATA PROCESSING RESULTS



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MTM-G & Pipeline Integrity Improvements

Anomaly #10 detail overview

GPS		Information about anomalies						PFG (Predicted Feature Group)	GR. 2	GR. 5	GR. 6
Latitude	Longitude	№ anomaly	Metal State	Risk Factor F	KP start [m]	KP end [m]	Length,m		Hoop part. Metal loss (* local character)	General Stress-deformed state	Hoop part. Metal loss (** General character)
		10	2	0.261	150.3	153.2	2.9	SDS	0.461	0.261	0.629

Governing anomaly

Governing anomaly, prediction feature

To be verified

Anomaly range	Category of technical condition	Risk Factor, F Range	Category of technical condition
1	INADMISSIBLE	0 – 0.2	INADMISSIBLE Section of urgent repair
2	ADMISSIBLE	0.2 – 0.55	ADMISSIBLE Section of scheduled repair
3	GOOD	0.55 – 1.0	GOOD Section can be operated without repair

MTM-G & Pipeline Integrity Improvements

MTM-G & Pipeline Integrity Improvements

Anomaly #7 detail overview

GPS		Information about anomalies							GR. 2	GR. 3	GR. 6
Latitude	Longitude	№ anomaly	Metal State	Risk Factor F	KP start [m]	KP end [m]	Length,m	PFG (Predicted Feature Group)	Hoop part. Metal loss (* local character)	Heat effecting (Weld anomaly)	Hoop part. Metal loss (** General character)
		7	2	0.511	117.3	121.1	3.8	Weld anomaly	0.85[illegible]	0.511	0.558

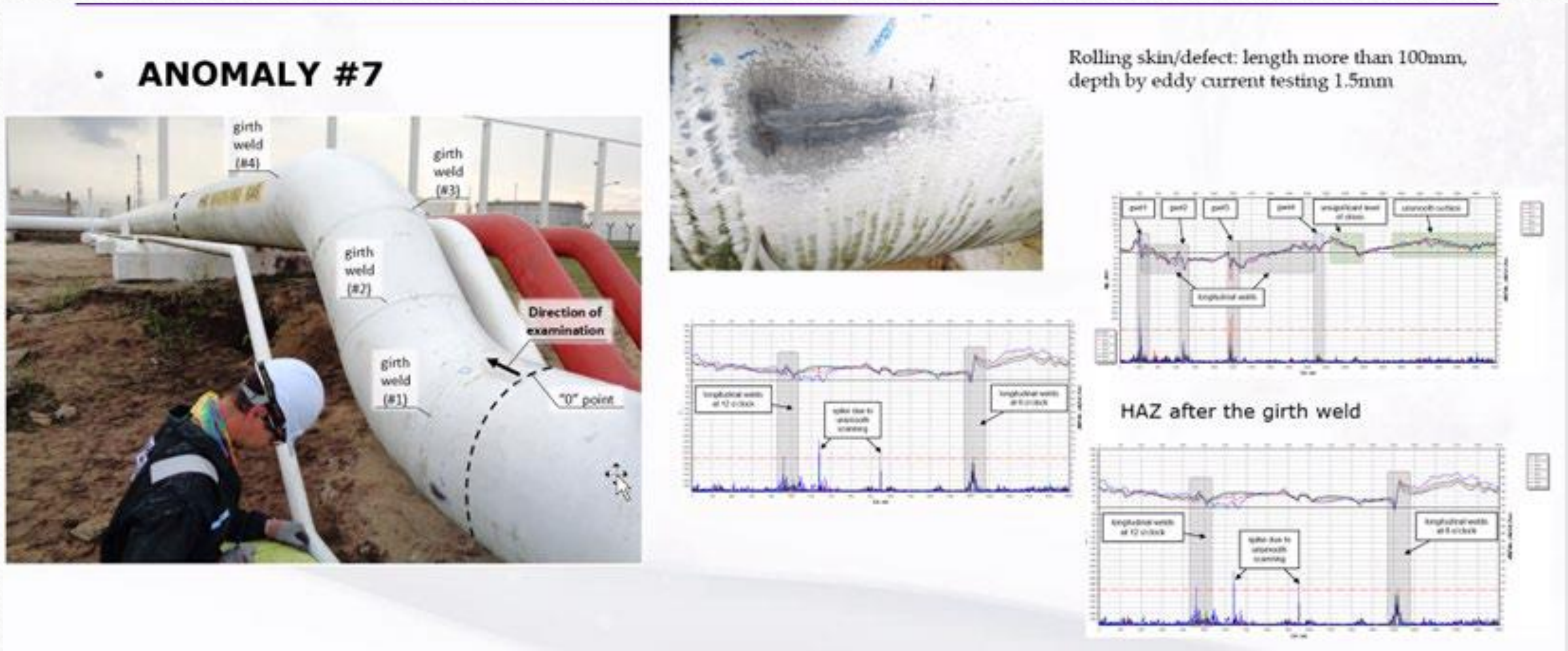
Governing anomaly

Governing anomaly, prediction feature

To be verified

Anomaly range	Category of technical condition	Risk Factor, F Range	Category of technical condition
1	INADMISSIBLE	0 – 0.2	INADMISSIBLE Section of urgent repair
2	ADMISSIBLE	0.2 – 0.55	ADMISSIBLE Section of scheduled repair
3	GOOD	0.55 – 1.0	GOOD Section can be operated without repair

MTM-G & Pipeline Integrity Improvements



MTM-G & Pipeline Integrity Improvements

Information about anomalies							GR. 1	GR. 2	GR. 3	GR. 4	GR. 5	GR. 6	GR. 7
№ anomaly	Metal State	Risk Factor F	KP start [m]	KP end [m]	Length,m	PFG (Predicted Feature Group)	Crack-like indication	Hoop part. Metal loss (* local character)	Heat effecting (Weld anomaly)	Mechanical impact (including Geometry)	General Stress-deformed state	Hoop part. Metal loss (** General character)	Inside Wall flaw (Lamination, inclusions)
1	3	0.756	18.4	22.4	4.0	Gr.5	-	-	-	-	0.756	0.874	-
1-1			0.6	3.4									
1-2			1.4	2.6									
1-3			3.6	0.4									
2	3	0.601	32.1	34.7	2.6	Gr.2	-	0.601	-	-	0.601	-	-
2-1			1.7	0.9									
3	2	0.443	37.9	41.7	3.8	Gr.3	-	-	0.443	-	0.443	0.493	-
3-1			0.9	2.9									
3-2			2.3	1.5									
3-3			3.0	0.8									
4	2	0.283	71.0	76.7	5.7	Gr.5	-	-	-	-	0.283	-	-
4-1			1.4	4.3									
4-2			2.6	3.1									
4-3			3.5	2.2									
5	3	0.906	80.7	83.0	2.3	Gr.5	-	-	-	-	0.906	-	-
5-1			1.3	1.0									
6	2	0.516	94.0	96.8	2.8	Gr.5	-	-	-	-	0.516	-	-
6-1			0.9	1.9									
6-2			2.1	0.7									
6-3			2.8	0.0									
7	2	0.511	117.3	121.1	3.8	Gr.3	-	0.858	0.511	-	0.611	0.558	-

MTM-G & Pipeline Integrity Improvements

Integrity log summary

№ anomaly	Metal State	Information about anomalies – Stress signature: Crack-flaw indication	Metal loss (* local character)	Weld anomaly	Geometry changes	Stress-deformed state	Metal loss (* general character)	Discontinuity/ Lamination	Risk Factor F	KP start [m]	KP end [m]	Length,m	Calculated Safe Operation Term: P=Psafe	Calculated Safe Operation Term: P=MOP	Stress Concentration Factor, SCF	PSAFE, [MPa]	Estimated Repair Factor, ERF	Nominal WT, mm	Hoop stress equivalent: Metal loss, [% of WT]
1	3	+	-	+	+	+	+	-	0,629	9,8	12,0	2,2	17	42	1,354	8,739	0,114	12,7	<20
2	2	-	-	-	-	+	-	-	0,375	15,4	16,8	1,4	8	18	1,805	6,555	0,153	12,7	-
3	2	+	+	+	+	+	+	-	0,255	19,5	23,2	3,6	5	11	1,895	6,242	0,160	12,7	27
4	3	-	-	+	-	-	-	-	0,936	48,8	50,5	1,8	49	122	1,039	11,383	0,088	12,7	-
5	3	+	-	+	+	+	+	-	0,575	64,8	65,6	0,8	15	35	1,521	7,776	0,129	12,7	<20
6	3	+	-	+	+	+	+	-	0,733	68,4	69,1	0,7	23	56	1,300	9,100	0,110	12,7	<20
7	3	-	-	-	-	+	-	-	0,822	69,9	70,5	0,6	30	75	1,187	9,964	0,100	12,7	-
8	3	-	-	+	-	+	-	-	0,952	77,9	79,3	1,4	53	133	1,029	11,499	0,087	12,7	-
9	3	-	-	+	-	-	+	-	0,839	85,0	86,3	1,3	32	80	1,137	10,407	0,096	12,7	<20
10	2	-	-	+	-	+	+	-	0,458	89,9	91,7	1,8	10	25	1,623	7,292	0,137	12,7	21
11	3	-	-	-	-	+	-	-	0,555	101,5	103,2	1,7	14	33	1,480	7,996	0,125	12,7	-
12	2	+	+	+	+	+	+	-	0,265	127,0	129,5	2,6	5	12	1,929	6,133	0,163	12,7	28
13	3	-	-	+	-	+	+	-	0,823	160,5	161,8	1,3	31	75	1,155	10,246	0,098	12,7	<20
14	3	-	-	-	-	+	-	-	0,936	241,9	243,6	1,8	49	122	1,040	11,376	0,088	12,7	-
15	3	-	-	-	-	+	-	-	0,852	276,1	276,6	0,4	34	83	1,158	10,219	0,098	12,7	-
16	3	-	-	-	-	+	-	-	0,839	289,5	291,6	2,1	32	80	1,122	10,550	0,095	12,7	-
17	2	-	-	+	-	+	+	-	0,366	323,1	325,9	2,8	8	18	1,716	6,896	0,145	12,7	24
18	2	-	-	+	-	+	+	-	0,421	348,7	350,6	1,8	9	22	1,680	7,044	0,142	12,7	23

Distribution by types

Integrity summary

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ANOMALIES RANKING (CAN BE CUSTOMIZED BY PROJECT)

BASIC RANKING:

Ranking of anomalies by F parameter:

Danger Degree, F	Rank of anomaly	Technical condition of pipe section with consideration of combination of metal defects with stresses	Recommendation
[0…0.2]	1	"Inadmissible", under threat of accident	Urgent repair
[0.2 … 0.55]	2	"Admissible" with low safety	Scheduled repair
[0.55 … 1]	3	"Good" With insignificant defects And stress concentration	Monitoring without repair

Ranking of anomalies by ERF parameter:

ERF		Technical condition of pipe section with consideration of combination of metal defects with stresses	Recommendation
≥1,0		"Inadmissible", under threat of accident	Repair during Tsafe (*)
<1,0		"Admissible" With insignificant defects And stress concentration	Monitoring without repair Or repair during Tsafe (*)

CUSTOMIZED RANKING:

Rank 1	ML > 60%
Rank 2	ML > 40% and ML < 60%
Rank 3	ML < 40%

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MTM-G Improvements

Current Approach Limitation

- POD is generally for all anomaly type i.e. SDS and Metal State
- Survey not recommended for the abandoned or low (0) pressure (no flow) pipelines where the POD will be at minimum
- Number of sensor is two, where the coverage survey is low and possibility of blind spot during inspection/survey
- Magnetic field measurement in planar-2D, refer figure
- Only complex stress (Von Mises stress) can be assessed, and pipeline integrity approach is based on the magnitude signal only;
- Single danger degree, F and SCF, and not considering type of failure or anomaly

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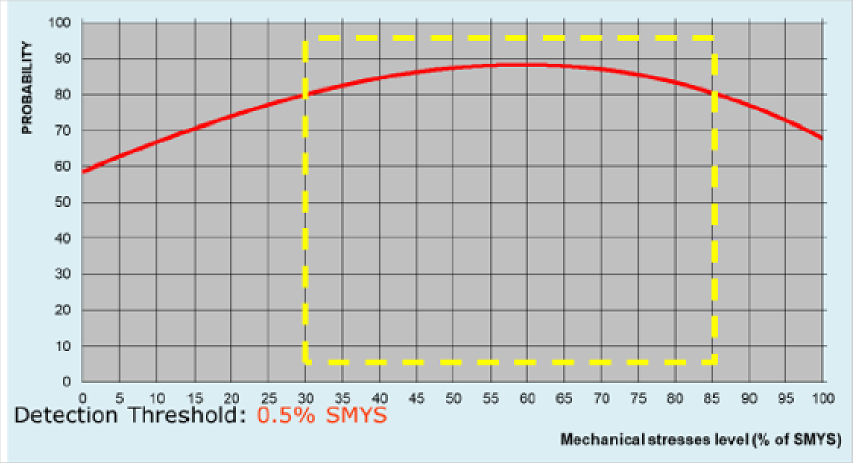
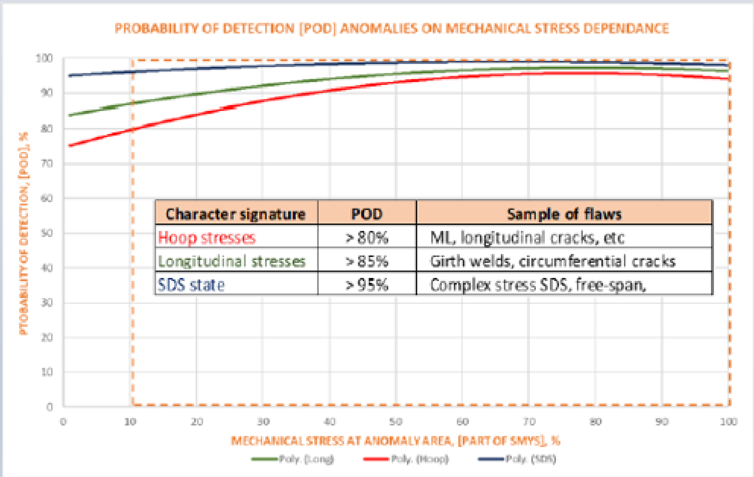
MTM-G Improvements

Item	Legacy	MTM-G
Survey/Inspection Distance to the pipeline	15D	25D
Reported anomaly type	SDS, Metal State Weld anomaly	Crack-like defects Metal loss (*) Weld anomaly Geometry change SDS Discontinuity
Low (0) pressure (no flow) pipelines	Low POD at 60%	Survey can be performed with minimum POD at -80% at hoop stress criteria -85% at longitudinal stress criteria -95% at SDS criteria

MTM-G Improvements

<table>
<tr><th>Item</th><th>Legacy</th><th>MTM-G</th></tr>
<tr><td>Probability of detection (POD)</td><td>
</td><td>
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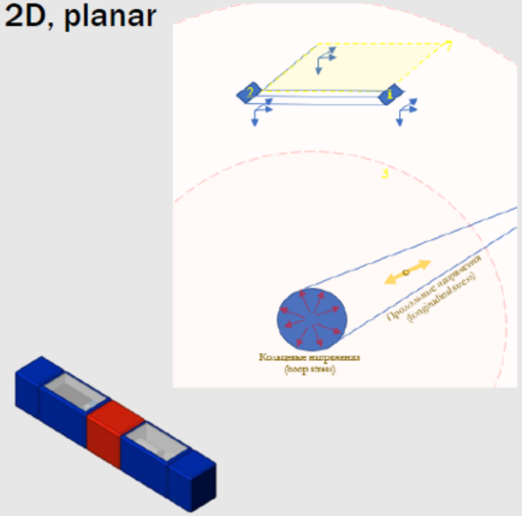
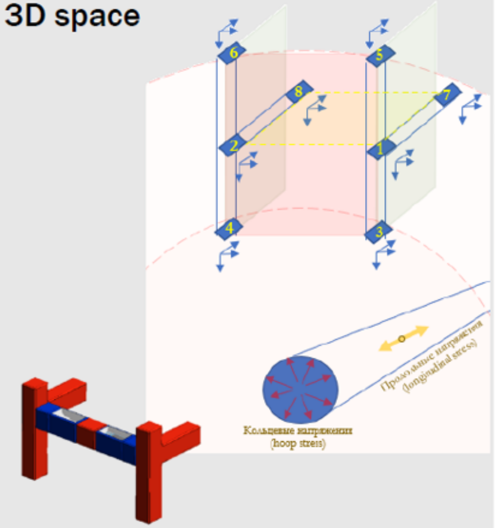
MTM-G Improvements

Item	Legacy	MTM-G
No of sensor utilization	2	6 (offshore, onshore, on air)
Magnetic field measurement, coverage	2D, planar 	3D space 

MTM-G Improvements

Item	Legacy	MTM-G
Stress criterion based on survey/inspection	Von Mises stress, magnitude signal	Each type of stress (hoop, longitudinal, any other kind of stresses and its combination can be assessed directly through direct gradient measurements
Danger degree, F and SCF	Single for all type of failure or anomaly	Multiple F and SCF will be provided based on failure criteria and anomaly 

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