Specifications and requirements for intelligent pig inspection of pipelines

Version 2.1, 6 November 98

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Contents

1. Introduction

This document specifies the operational and reporting requirements for tools which use ultrasonic or magnetic flux leakage principles and which detect metal loss and/or cracking during their passage through the bore of steel pipelines. The tools may pass through the pipeline driven by the flow of fluid or may be towed by a vehicle or cable. The tools may be automatic and self-contained or may be operated from outside the pipeline via a data and power link.

The document has been reviewed and subscribed by the members of the Pipeline Operator Forum who are listed in Appendix 1. It is the intention to review the document in 2002.

2. Standardisation

2.1 Definitions

Anomaly:	An indication, generated by non-destructive examination of an irregularity or deviation from sound weld or base pipe material, which may or may not be an actual flaw.
Arc strike:	Localised points of surface melting caused by an electrical arc (also referred to as hot spot).
Construction feature:	Feature that arises during pipe manufacture, transport or constructing of the pipeline, including a girth weld anomaly, arc strike and grinding.
Corrosion:	An electrochemical reaction of the pipe wall with its environment causing a loss of metal.
Crack:	A planar, two-dimensional feature with displacement of the fracture surfaces.
Dent:	Distortion of the pipe wall resulting in a change of the internal diameter but not necessarily resulting in localised reduction of wall thickness.
Detection threshold:	The minimum detectable metal-loss.
Feature:	An indication, generated by non-destructive examination, of an anomaly, change in nominal wall thickness, casing, reference magnet, pipeline fixture or fitting including tees, offtakes, valves, bends, anodes, buckle arrestors, external supports, ground anchors, repair shells and CP connections.
Grinding:	Reduction in wall thickness by removal of material by hand filing or power disk grinding.
Gouge:	Mechanically induced metal-loss, which causes localised elongated grooves or cavities.
Heat affected zone:	The area around a weld where the metallurgy of the metal is altered by the rise in temperature caused by the welding process. For the purpose of this specification it is considered to be within 3A of the centre line of the weld, where “A” is the geometrical parameter related to the wall thickness.
Intelligent pig:	A pig that can perform a non-destructive examination.

Metal-loss feature:	An area of pipe wall with a measurable reduction in thickness.
Midwall feature:	Any feature which does not run out to either the internal or external surface.
Measurement threshold	The depth of metal-loss or remaining wall thickness from which the width “W” and length “L” of the defect are measured.
Nominal wall thickness:	The wall thickness required by the specification for the manufacture of the pipe.
Pig:	A device which is driven through a pipeline by the flow of fluid, for performing various internal activities (depending on the pig type) such as separating fluids, cleaning or inspecting the pipeline.
Pig Trap:	An ancillary item of pipeline equipment, with associated pipework and valves, for introducing a pig into a pipeline or removing a pig from a pipeline.
Pipeline:	A system of pipes and other components used for the transportation of fluids between (but excluding) plants. A pipeline extends from pig trap to pig trap (including the pig traps), or, if no pig trap is fitted, to the first isolation valve within the plant boundaries or a more inward valve if so nominated.
Pipe mill feature:	A feature that arises during manufacture of the pipe, as for instance a lap, sliver, lamination, non-metallic inclusion, roll mark and seam weld anomaly.
Probability of Detection:	The probability of a feature being detected by the intelligent pig.
Probability of Identification:	The probability that a feature will be detected and correctly classified by the intelligent pig.
Reference wall thickness:	The actual undiminished wall thickness surrounding a feature.
Reporting threshold:	A parameter, which defines whether or not a metal loss feature will be reported. The parameter may be a limiting value on the depth of metal-loss or it may be a function of depth width and length of a metal-loss feature
Sizing accuracy:	Sizing accuracy is given by the interval within which a fixed percentage of all metal-loss features will be sized. This fixed percentage is stated as the confidence level.
Spalling:	Abrasion of the pipe surface resulting in shallow surface laps and possibly hardening of the material below.
Weld feature:	Feature in the body or the heat affected zone of a weld.

2.2 Abbreviations

A:	Geometric parameter
d:	Maximum metal-loss feature depth
ERF:	Estimated repair factor
L:	Metal-loss feature length in the axial direction
MOP:	Maximum operating pressure
MFL:	Magnetic flux leakage
NDE:	Non-destructive examination
POD:	Probability of detection
POI:	Probability of identification
t:	Wall thickness
W:	Metal-loss feature width in the circumferential direction

2.3 Geometrical parameters and interaction of metal-loss features

Geometrical parameters of metal-loss features are length "L", width "W", depth "d" and reference wall thickness.

The start and endpoint of a metal-loss feature is determined by the measurement threshold as indicated in Figure 1. The length, “L”, of an individual metal-loss feature is given by its projected length on the longitudinal axis of the pipe. The width, “W”, of an individual metal-loss feature is given by its projected length on the circumference of the pipe. The measurement threshold may be set at the detection threshold or at some independent value according to the pipeline characteristics.

The intelligent pigging contractor should specify the measurement threshold. If no value is specified then the measurement threshold shall be taken at 5% with respect to the reference wall thickness.

The depth of the metal-loss “d” is determined by the maximum wall loss in a metal-loss feature and can be given as a depth from or percentage of the reference wall thickness.

Where no metal-loss feature interaction rules are specified, two individual metal-loss features interact and shall be clustered when the axial spacing between the metal-loss feature edges is less than the smallest metal-loss feature length and the circumferential spacing is less than the smallest metal-loss feature width.

The geometrical parameter A is linked to the NDE methods in the following manner:

If $t < 10$ mm then $A = 10$ mm
If $t \geq 10$ mm then $A = t$

2.4 Metal-loss feature typing

Metal-loss features are classified into:

- Pipe mill features
- Construction features
- Gouging
- Corrosion

The measurement capabilities of non-destructive examination techniques depend on the geometry of the metal-loss feature. Geometrical metal-loss feature classes have been defined as shown in Figure 2 to allow a proper specification of the measurement capabilities of the intelligent pig. Each feature class permits a large range of shapes. Within that shape a reference point is defined at which the POD is specified. The client may request that the contractor specifies the POD as a continuous curve of constant POD and L on a graph where the axes are d and W. Recommended values are POD=90% and (L=A and/or L=3A).

Metal-loss type	Definition	Reference point for the POD in terms of L x W
General:	{[W = 3A] and [L = 3A]}	4A x 4A
Pitting:	{([1A = W < 6A] and [1A = L < 6A] and [0.5 < L/W < 2]) and not ([W = 3A] and [L = 3A])}	2A x 2A
Axial grooving:	{[1A = W < 3A] and [L/W = 2]}	4A x 2A
Circumferential grooving:	{[L/W = 0.5] and [1A L < 3A]}	2A x 4A
Pinhole:	{[0 < W < 1A] and [0 < L < 1A}	½A x ½A
Axial slotting:	{[0 < W < 1A] and [L = 1A]}	2A x ½A
Circumferential slotting:	{[W = 1A] and [0 < L < 1A]}	½A x 2A

An even distribution of length, width and depth shall be assumed for each metal-loss type to derive at a statistical measurement performance on sizing accuracy.

The reference point in the table above is the point at which the POD is specified.

2.5 Crack feature typing

In some cases the scope of work for the inspection will include the detection of cracking in addition to the detection of metal-loss. Where this is the case the cracking may be classified into:

- Girth weld cracking
- Longitudinal seam weld cracking
- Stress corrosion cracking
- Hydrogen induced cracking (HIC)

2.6 Estimated repair factor

The estimated repair factor (ERF) is defined as:

$$ERF = MOP/P_{safe}$$

Where P_{safe} is the safe operating pressure as calculated by a metal-loss feature assessment method.

2.7 Resolution of measurement parameters

The following resolution shall be used for the measurement parameters:

Definition	Metric units	Imperial units
Log distances:	0.001 m	feet & inches
Feature length and width:	1 mm	0.1 inches
Feature depth:	0.1 mm or 1%	0.01”or 1%
Reference wall thickness	0.1 mm or 1%	0.01” or 1%
Orientation:	1° or 15 minutes	15 minutes
ERF:	0.01	0.01
Magnetic field H:	1 Am^{-1}	Oersted
Axial sampling distance:	0.1 mm	0.01 inches
Circumferential sensor spacing:	0.1 mm	0.01 inches
Tool speed:	0.1 m/s	0.1 ft/sec
Temperature:	1 °C	F
Pressure:	0.01 MPa	psi

3. Tool specifications

Tool specification shall include:

- Wall thickness range
- The magnetic field strength H in Am^{-1} as function of wall thickness (only for MFL pigs)
- Speed range
- Temperature range
- Maximum pressure
- Minimum pressure for gas pipelines
- Minimum bend radius
- Minimum internal diameter
- Tool length weight and number of bodies
- Minimum length of pipeline that can be inspected in one run (may be coupled to run times and state of the pipeline)
- Axial sampling frequency or distance
- Nominal circumferential sensor spacing
- Location accuracy of the features with respect to the upstream girth weld, the upstream marker and the orientation in the pipe

The measurement specification shall include the Tables 1 to 3. Optionally, pinhole features, axial slotting features and circumferential slotting features can be added to the tables.

It is recognized that the probability of detection of a feature is highly dependent on pipe wall magnetization for MFL pigs. Tables 2 and 3 shall therefore be linked, in case of MFL pigs, to pipe wall magnetization ranges whereby the specifications shall apply for the minimum pipe wall magnetization and also to the pipeline make (i.e. seamless pipe vs longitudinally seam-welded pipe).

Where the contractor uses automatic sizing of metal-loss features and this sizing has a reduced specification, the automatic sizing specification shall be included in Tables 4 and 5.

If crack detection is possible and is included in the inspection scope of work, the contractor shall provide the following parameters:

- Minimum depth and length for the detection of a crack
- The confidence level for the detection of this minimum crack
- The accuracy of sizing of crack length and depth
- The confidence level for the sizing performance

4. Reporting requirements

The requirements herein may be changed at the client's request.

The field report shall contain a statement of the contractor on the quality of the inspection run.

The final inspection report shall contain the following information:

- Tool operational data
- Pipe tally
- List of features
- Summary and statistical data
- Fully assessed feature sheets
- Defect assessment method

4.1 Tool operational data

The tool specifications shall be given. In addition the following operational data shall be provided:

- The data-sampling frequency or distance
- The detection threshold
- The reporting threshold, normally taken at 90% POD if not specified otherwise
- A tool velocity plot over the length of the pipeline
- Optionally, a pressure and/or temperature plot over the length of the pipeline
- In case of MFL pigs, the magnetic field strength H in Am^{-1}
- In case of ultrasonic pigs, echo loss statistics

The tool operational data shall indicate whether the tool has functioned according to specification. It shall detail all locations where the measurement specifications are not met.

4.2 Pipe tally

The pipe tally shall contain:

- Numbering of all pipe joints and listing of all girth welds by log distance
- Listing of each joint length
- Listing of all pipeline installations including fittings, valves, tees, markers, CP points, etc.

The joint numbering shall start at the first joint after the first line valve. The zero position of the log distance shall be the center-point of the first line valve.

The pipe tally list shall contain the following fields:

- Log distance in m
- Joint number giving log distance at upstream girth weld
- Joint length in m
- Description of installation

For ultrasonic tools, the pipe tally shall give the reference wall thickness of each pipe joint as measured by the tool. Where there is a variation in the reference wall thickness over the length of the joint, the most frequently measured reference wall thickness shall be given.

4.3 List of features

All features with dimensions above the reporting threshold at 90% POD or above a reporting threshold as subscribed in the Technical Scope of Work of the Contract shall be reported in the List of Features. The List of Features shall be compatible with standard ASCII files (e.g. DB IV compatible) and shall contain the following input fields:

- Log distance
- Joint number
- Nominal pipe wall thickness or reference wall thickness as measured by the tool.
- Feature description including type modifiers as for instance adj.G.W. (Adjacent to Girth Weld)
- Distance to upstream girth weld
- Orientation
- Feature length
- Feature width
- Feature depth
- ERF
- Internal/external/mid-wall indication

The accuracy of measurement in the above fields will be to the automatic sizing specification.

4.4 Summary and statistical data

The summary data shall contain a listing of:

- Total number of metal-loss features
- Number of internal metal-loss features
- Number of external metal-loss features
- Number of general metal-loss features
- Number of pits
- Number of axial and circumferential grooves
- Number of metal-loss features with depth 0 - 9%t
- Number of metal-loss features with depth 10 - 19%t
- Number of metal-loss features with depth 20 - 29%t
- Number of metal-loss features with depth 30 - 39%t
- Number of metal-loss features with depth 40 - 49%t
- Number of metal-loss features with depth 50 - 59%t
- Number of metal-loss features with depth 60 - 69%t
- Number of metal-loss features with depth 70 - 79%t
- Number of metal-loss features with depth 80 - 89%t
- Number of metal-loss features with depth 90 - 100%t
- Number of metal-loss features with $0.6 = ERF < 0.8$
- Number of metal-loss features with $0.8 = ERF < 0.9$
- Number of metal-loss features with $0.9 = ERF < 1.0$
- Number of metal-loss features with $ERF = 1.0$

The following histograms shall be provided over the entire pipeline length:

- Number of metal-loss features in 500-m sections
- Number of metal-loss features in 500 m sections with depth = 0.4t
- Number of metal-loss features in 500 m sections with depth = 0.6t
- Number of metal-loss features in 500 m sections with ERF = 0.8
- Number of metal-loss features in 500 m sections with ERF = 1.0

The following plots shall be provided:

- Sentenced plot including ERF = 1 curve of metal-loss feature length against metal-loss feature depth showing all metal-loss features for the predominant wall thickness
- Orientation plot of all metal-loss features over the full pipeline length
- Orientation plot of all internal metal-loss features over the full pipeline length
- Orientation plot of all external metal-loss features over the full pipeline length
- Orientation plot of all metal-loss features as function of relative distance to the closest girth weld

4.5 Fully assessed feature sheets (dig up sheets)

Fully assessed feature sheets shall be provided as a minimum for the 10 most serious metal-loss indications. Selection of the most serious metal-loss indications can be based on depth or pressure, to be defined in Technical Scope of Work in the Contract. If not specified otherwise, the selection of 5 features will be depth based and the other 5 pressure based.

Fully assessed feature sheets shall contain the following information to the full sizing specification:

- Length of pipe joint and orientation of longitudinal seam (when present);
- Length and longitudinal seam orientation of the 2 upstream and 2 downstream neighbouring pipe joints;
- Distance of upstream girth weld to nearest upstream marker;
- Distance of upstream girth weld to nearest downstream marker;
- Distance of metal-loss feature to upstream girth weld;
- Distance of metal-loss feature to downstream girth weld;
- Orientation of metal-loss feature;
- Feature description and dimensions;
- Internal/external/mid-wall indication.

Table 1: Identification of features

Feature	Yes POI>90%	No POI<50%	May be 50%≤POI≤90%
Internal/external discrimination			
Metal-loss feature			
Metal-loss pipe mill feature			
Mid-wall feature			
Grinding			
Gouge			
Dent			
Dent with metal-loss			
Spalling			
Axial crack			
Circumferential crack			
Eccentric pipeline casing			
Sleeve repair			
Fitting			
Valve			
Tee			
Bends (5D or less)			

Table 2: Full detection and sizing accuracy for metal-loss features in body of pipe

	General metal-loss	Pitting	Axial grooving	Circumf. grooving
Depth at POD=90%				
Depth sizing accuracy at 80% confidence				
Width sizing accuracy at 80% confidence				
Length sizing accuracy at 80% confidence				

Table 3: Full detection and sizing accuracy for metal-loss features in girth weld or heat affected zone

	General metal-loss	Pitting	Axial grooving	Circumf. grooving
Depth at POD=90%				
Depth sizing accuracy at 80% confidence				
Width sizing accuracy at 80% confidence				
Length sizing accuracy at 80% confidence				

Table 4: Automatic detection and sizing accuracy for metal-loss features in body of pipe

	General metal-loss	Pitting	Axial grooving	Circumf. grooving
Depth at POD=90%				
Depth sizing accuracy at 80% confidence				
Width sizing accuracy at 80% confidence				
Length sizing accuracy at 80% confidence				

Table 5: Automatic detection and sizing accuracy for metal-loss features in girth weld or heat affected zone

	General metal-loss	Pitting	Axial grooving	Circumf. grooving
Depth at POD=90%				
Depth sizing accuracy at 80% confidence				
Width sizing accuracy at 80% confidence				
Length sizing accuracy at 80% confidence				

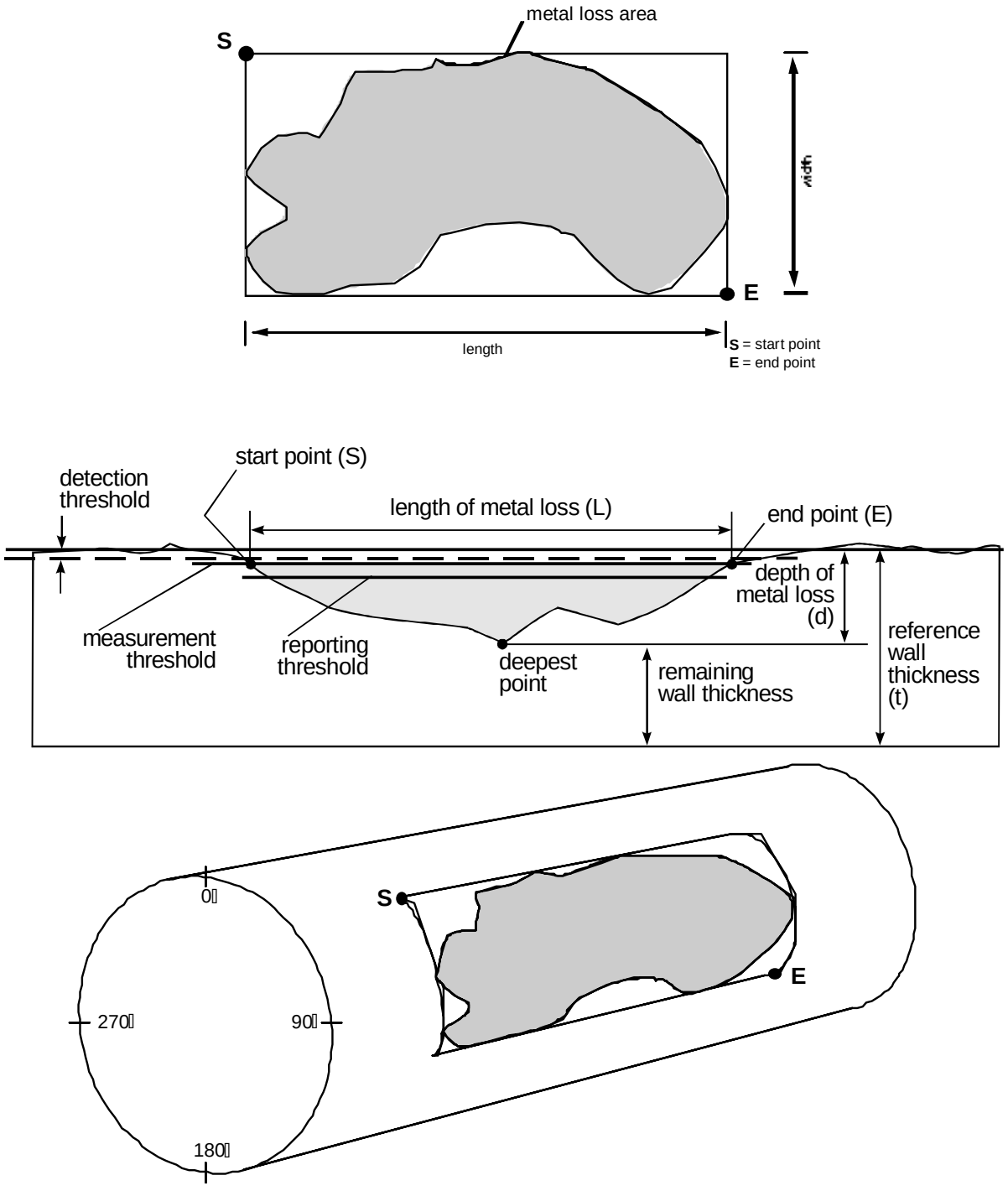

Figure 1: Location and dimensions of metal-loss features

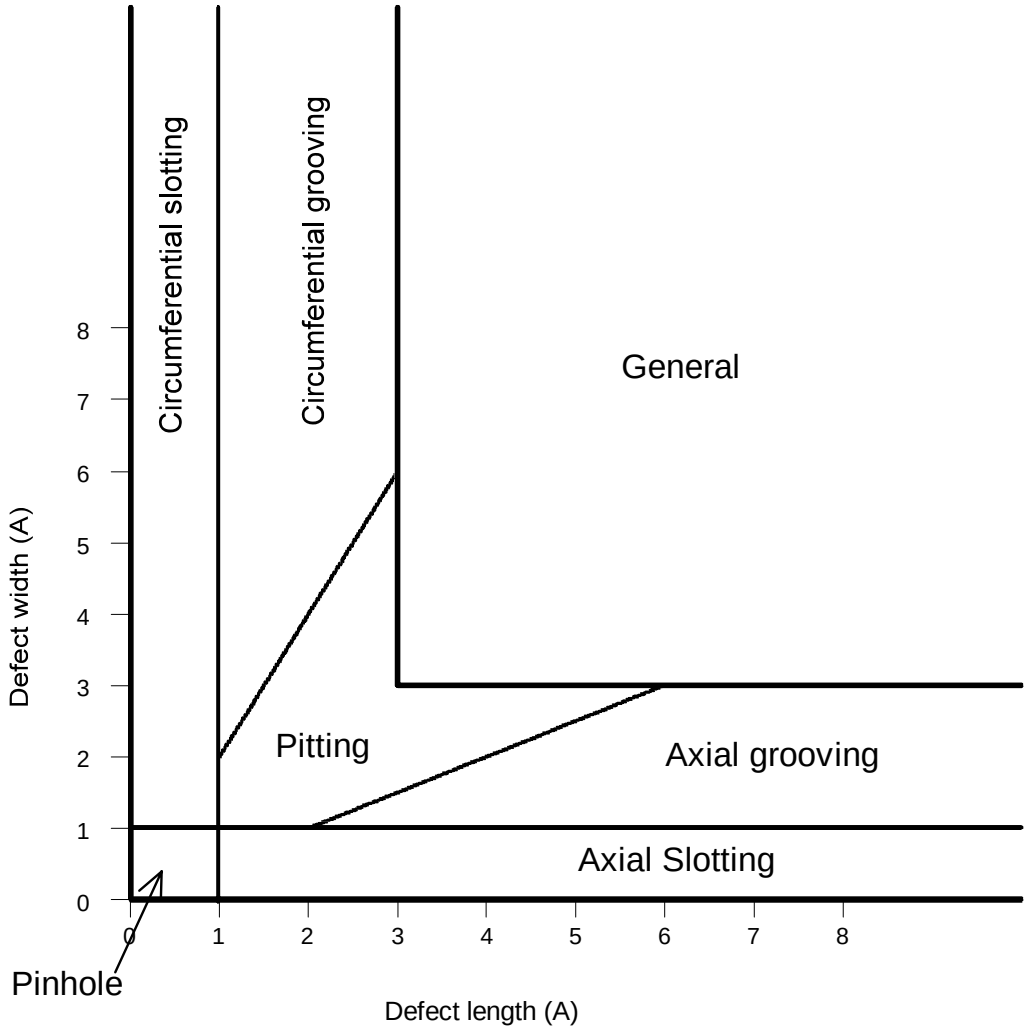

Figure 2: Graphical presentation of metal-loss feature type definitions

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