_inline inspection (ILI) geometry tools have been a staple of pipeline integrity management programmes for many years. Historically, these tools are used to locate dents, ovalities, or other indications of third-party damage, as well as to identify fittings or restrictions that could hinder subsequent pig passage. Apart from these traditional types of features, other features can also prove problematic in some cases.

For example, in some pipeline joints there is the potential of the pipe diameter becoming inadvertently but permanently increased, either before installation or due to hydrotesting or some other in-service condition (Figure 1). While the pipe diameter expansion by itself may not be an integrity threat, it may indicate that the material properties of the native pipe may not be as specified, which could apply to other joints within the pipeline as well. Recently, similar integrity threats have arisen related to potential issues with newly manufactured pipe.

In May 2009, the Pipeline and Hazardous Materials Safety Administration (PHMSA) in the United States issued a safety advisory related to the potential that some recently milled pipe might have tensile properties below specified minimums (see PHMSA-2009-0148; Pipeline Safety: Potential Low and Variable Yield and Tensile Strength and Chemical Composition Properties in High Strength Line Pipe). The advisory described some of the field symptoms associated with the condition, “... several recently installed natural gas transmission pipeline systems experienced field hydrostatic test failures or excessively expanded pipe joints of large diameter, microalloyed high grade line pipe.”

The advisory then suggested that a thorough review of pipe specification and deformation tool results should be conducted, to ensure that installed pipe was in conformance to American Petroleum Institute (API) 5L requirements. While PHMSA jurisdiction is limited to the North America, the potential for pipe of lower-than-specified strength to enter the new construction market is a global concern. With today’s market for line pipe largely independent of national borders, the need to locate affected joints of pipe could arise anywhere in the world.
Addressing the need
In response to this need, T.D. Williamson, Inc. (TDW) has developed additional advanced techniques for use with its MAGPIE® high-resolution deformation (DEF) tool systems (Figure 2a and 2b), to specifically address the location and characterisation of expanded pipe. These DEF tool systems feature:

- Mechanical measurement arms in direct contact with the pipe wall.
- High circumferential channel count.
- High resolution sensors able to detect minute pipe geometry changes.

These systems have an established track record of accurate characterisation of dents, wrinkles, buckles and ovalities. In addition, DEF tools are designed to accurately measure diameters that are larger than the nominal pipe diameter, making them particularly well suited for characterising expansions. Software tools have been developed to facilitate that characterisation.

The goal of TDW's efforts in the inspection of large diameter pipe for possible expansions is simple enough; locate and accurately measure localised areas of increased inside diameter (ID). The TDW DEF tool is capable of creating data necessary to find and quantify very small changes in pipe ID. However, the task of discriminating and characterising ID differentials turns out to be more involved than simply finding areas where the actual ID is greater than the nominal ID.

There are several variables that might affect the ID of any given joint of pipe and have a direct influence on actual expansion measurement. All of these variables contribute to some extent to variations in pipe ID, and make it difficult to determine a true nominal pipe diameter. For example, the following tolerances are based on API 5L specifications and are important to consider if attempting to determine a nominal ID:

![Figure 1. Expanded pipe as found in the field.](image1)

![Figure 2a. Deformation (DEF) tool designed and utilised by T.D. Williamson, Inc.](image2a)

![Figure 2b. Deformation (DEF) tool designed and utilised by T.D. Williamson, Inc.](image2b)

![Figure 3. Bore plots and cross-section views for three consecutive joints of a 36 in. pipe. The middle joint contains a verified 2% expansion.](image3)
Diameter - positive tolerances can translate to as much as 0.75% in the body of a joint of 36 in. pipe and 0.25 in. for 42 in. pipe.

Out of roundness (ovality) - up to 0.5 in. difference between the maximum diameter and minimum diameter is allowable from the mill. In practice it is not uncommon to see a "normal" ovality of over 0.5% in buried large diameter pipe.

Wall thickness - some variation of wall thickness is allowable and also has a small effect on the measuring of pipe ID.

Refining the method
After considerable experimentation with the data from early inspection runs, it was concluded that the best method of both locating and measuring expanded diameters was to calculate the amount of ID change within a single joint of pipe. Due to the inherent variables, neither a maximum diameter nor an established constant nominal diameter is used for identification of expansions. Instead, enhancements were implemented within TDW's analysis software to calculate multiple diameter measurements, and establish a baseline ID for every pipe joint. This has proven to be a very accurate method of detecting and quantifying expansions with excellent repeatability in multiple inspections of the same pipeline segment.

Various diameter values are derived from analysing the data from the sensor arms on the DEF tool at any given cross section of pipe, including maximum diameter, minimum diameter, and average diameter. Optimal bore estimation techniques applied to the cross section data negate any ovality affect on the diameter calculations, and have the added benefit of increasing the accuracy and repeatability of the DEF tool measurements.

An automated scan using TDW's analysis software calculates and records diameter calculations for every joint within the pipeline segment, establishing a baseline for each joint. When comparisons of the maximum diameter values versus the baseline for the joint reach a specified threshold agreed upon by the pipeline operator, the affected joint is flagged for further manual review. The reporting threshold is generally based on the API 5L tolerances. The experience from approximately 1700 miles of inspection specifically aimed at detecting expansions is that normal variations in average diameter of greater than 1/8 in. are quite common in a straight pipe.

There is some concern about the possibility of full joint expansions comprising the entire length of a joint or actually continuing into an adjacent joint. This condition would render a baseline calculation erroneous and make comparisons within the joint ineffective. At this time no case has been encountered where the calculated diameters have not returned to a nominal state at or near the girth welds. In these cases, the nominal state occurs very close to either the upstream or downstream girth weld, and may require more detailed analysis. If the accuracy of the measurement becomes a concern in cases that appear to be a nearly full joint expansion, the baseline averages of upstream and downstream joints can be employed.

Analysing the data
After flagging those joints with a calculated value greater than the threshold, a data analyst reviews all of the flagged locations in the analysis software. Valves, tees, taps and manufactured bends obviously have some effect on diameter measurements; these are eliminated from the list of potential expansions. The final results of the expansion evaluation are reported as a differential value for each affected joint in inches and as a percent of nominal pipe size. A final listing of joints with possible expansions is usually combined into a standard DEF inspection report.

A valuable tool in the identification and evaluation of pipe expansion is a graphical representation of diameter values plotted against absolute distance. Figure 3 represents three consecutive joints of 36 in. pipe. The first and third are typical normal joints, with the middle joint containing a verified expansion of approximately 2%. TDW's software team created a programme to automatically generate these graphs and to enable data analysts to customise the graphs to meet client-specific requirements.

For each joint, a cross-section view of the pipe is shown sampled at the location of the arrow on the plot. In these cross section views, the orange circle is nominal ID, the black dashes represent the tool's individual sensors, and the blue circle is the smallest diameter circle that circumscribes the sensors. Note that the expansion still appears round in shape and that the bore plots identify the expansion far more effectively than do the cross section views.

Field verifications of reported expansions have been very positive. PI tape field measurements have reported diameter variation results within a few hundredths of an inch of the TDW reported bore changes, a tolerance of less than 0.1% of nominal OD. In all cases to date, the analysis process has provided excellent results in identifying and quantifying expansions.

In summary, while geometry ILI tools are traditionally instrumental in detecting pipeline restrictions and damage from external forces, expansion of the pipe diameter from internal forces is yet another feature that is identified using the same technology. With the chance that even a newly constructed pipeline contains expansions due to below specification pipe material, a properly designed ILI tool and accompanying software are instrumental in accurately identifying and quantifying expanded pipe.