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Digital imaging and laser measurement of paste pipe wear

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Abstract

The wear of paste fill pipes is affected by a range of factors and can be difficult to predict. Tailings properties, paste mixture, pipe material and geometry as well as human factors regarding the operation of plant may all affect pipe wear. For this reason monitoring the condition of pipework through regular inspection is good practice in any paste fill infrastructure maintenance program. Recent advances in digital imaging recognition algorithms make it possible to perform real-time internal pipe measurement and image-capture to quickly collect valuable pipe condition data with minimal plant downtime. A paste pipe measuring instrument, called HoloSense, which can be lowered down vertical paste pipes is described here and examples are given of measurements from regular inspections on paste fill borehole pipes at Newmont's Tanami Gold Mine since December 2015. The instrument uses a laser source together with a holographic diffraction grating and conical mirror to illuminate the inside of the pipe with a ring of light. This ring is imaged with a centrally located camera and measurements of internal wear are determined automatically in real time and logged for later detailed analysis. The mathematical image analysis system is the main innovation with the instrument and allows measurements of pipe wear to an absolute accuracy of better than 1 mm and a resolution of 0.2 mm. Up to 360 Independent points are measured on the circumference of the ring giving an excellent resolution of wear. In the direction of the pipe axis, measurements are taken typically every 10 mm in a reconnaissance survey where the instrument is lowered down the pipe at its maximum winch speed of 0.3 m/s. By slowing down the winch speed, detailed measurements of highly worn areas give information every 1 mm in the pipe axis direction.

1 Introduction

Paste pipes are an essential and expensive component of many underground mining operations and failure of the pipe can result in loss of productivity (Belem and Benzaazoua, 2008). Wear of the pipe can lead to eventual blow out and paste leaking into the void between the pipe and the surrounding country rock. This can cause pipe blockage, depending on the mechanism of the failure and may also result in the pipe being effectively cemented into rock making removal impossible, and leakage can be a safety hazard in some cases.

The wear of paste pipes is difficult to predict and depends upon tailings properties, paste mixture, pipe material and geometry as well as human factors regarding the operation of plant. Wear is often very uneven and small zones of a few tens of centimeters in length can exhibit dangerous wear but on either side of this zone, the pipe is in good condition. In order to extract the greatest life from the pipe, without risking costly failure, a system of routine measurement is useful to plot the wear and to extrapolate the time to failure so that maintenance procedures can be planned and implemented.

The measurement of internal pipe wear is a problem in many industries and multi-finger calipers are a commonly used method of obtaining internal pipe measurements (Maxted et al., 1995; Yin et al., 1994) especially in the oil and gas industry. Similar multi-finger calipers are also often used on so called "smart PIGs" for gathering dimensional data of gas pipeline (Bickerstaff et al., 2002). The multi-fingered calipers on the market today may use in excess of 50 spring loaded levers (arranged radially) to brush against the inside of the pipe and the position of the levers is logged as a function of the distance along the pipe (GoWell, 2016).

Visual pipe inspection using video cameras is not a new concept and has been used since video camera technology first became widely available (Hudertmark and Davey, 1981). Only recently however has computer processing power reached a level at which it is possible to perform complex real-time image processing on high-quality imagery, thereby adding valuable quantitative data to the video footage. In this paper we describe an optical system of pipe measurement, which uses advanced image recognition algorithms to determine the pipe internal dimensions. Examples of data from routine surveys at the Newmont Tanami Mine in Australia are given to demonstrate the capabilities of the instrument.

2 The HoloSense instrument

2.1 Instrument design

HoloSense is the name given to the borehole pipe inspection instrument developed specifically for measuring paste pipe wear (Figures 1 and 2). The instrument consists of a laser fitted with a holographic diffraction grating which produces a conical light source that falls on a conical mirror which in turn reflects the light to form a ring of light on the inside of the pipe. A machine vision camera with a wide-angle lens takes an image of the light ring and sends the data to the surface along a 500 m fiber optic cable mounted on a winch driven by a variable speed electric motor. The fiber optic cable passes over a wheel upon which is mounted a tilt sensor that measures the rotation of the wheel. The rotation of the wheel determines the position down the pipe of the instrument. Data from the tilt sensor is transmitted to the data acquisition computer via a wireless link.

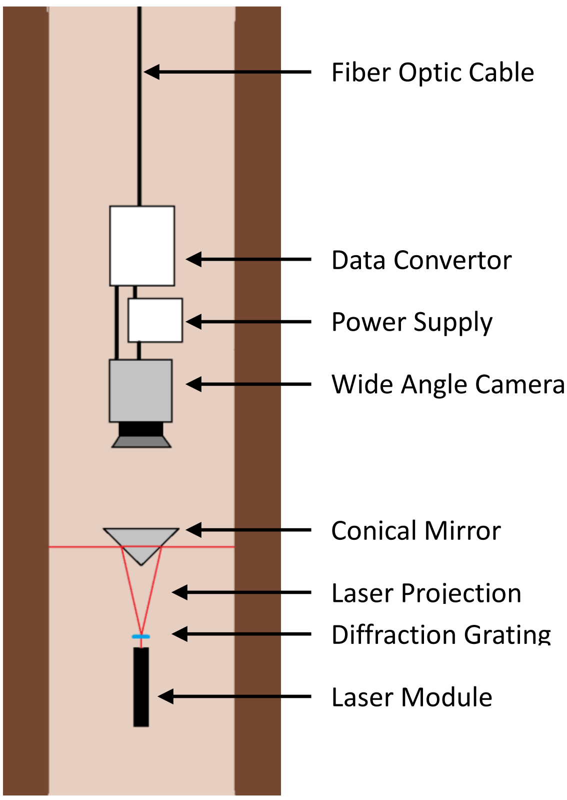


Figure 1 Diagram of the HoloSense instrument showing optical components and camera

Figure 2 Photograph of the HoloSense

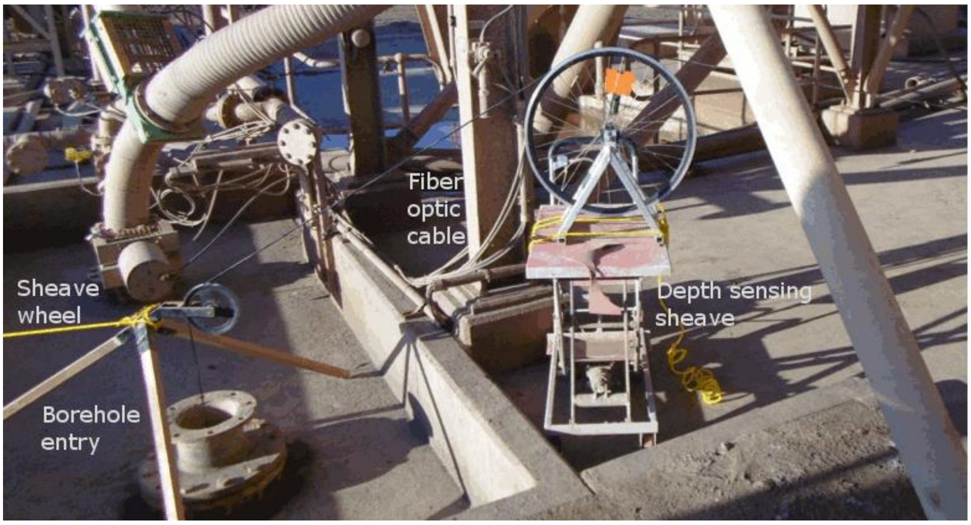


Figure 3 Distance counter wheel above the paste pipe surface opening

The dimensions of image of the ring can be used to infer the internal diameter of the pipe and determine the size of any anomalies from the average internal diameter. A typical image is shown in Figure from which can be seen the laser light ring which is slightly out-of-round due to wear in the pipe. The three metal rods which secure the light source below the camera can be seen projecting radially from the center of the image.

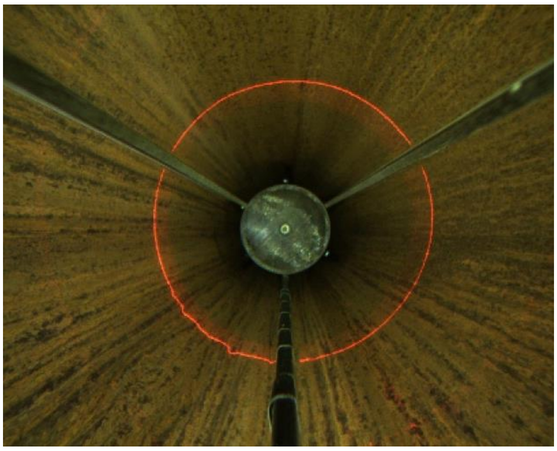


Figure 4 Laser ring projected on the wall of a pipe showing wear at bottom left

2.2 Testing location

Newmont's Tanami Gold Mine is located in the Tanami Desert in the Northern Territory, Australia. The gold is mined using sub-level open stoping with paste backfill. Two parallel, mostly vertical boreholes provide a link between paste plant and the subsurface paste delivery infrastructure. 300 mm ID steel casings run the length of both boreholes and are cemented into position. Smaller diameter paste pipe runs inside each bore casing, fixed with a surface flange only.

The first of these paste pipes, herein referred to as “Borehole pipe 1”, is DN200 Schedule 120 steel pipe OD 219.1 mm, wall thickness 18.26 mm giving a nominal ID of 182.58 mm. Jointing is by welding at 12 m intervals. The pipe has worn through and has not been used since February 2015.

The second paste pipe, “Borehole pipe 2”, has been used as the primary paste delivery pipe since the failure in borehole pipe 1 was identified. Until September 2016, this pipe was DN200 Schedule 120 steel with welded joints, however this has since been replaced by a ceramic lined pipe with API threaded couplings. The pipe itself is DN200 Schedule 40 steel and is lined with a mixture of cast epoxy and ceramic beads for a nominal ID of 175 mm.

At the time of writing, five inspections have been performed over a period of 11 months.

3 Example measurement

3.1 Typical measurements

When collecting data using the HoloSense instrument and software, the user is provided with a real-time, wide-angle image from the camera as well as measurement data as shown in Figure 5. The image is over-laid with values for minimum, maximum and average diameter (top left of image), and the location of the red laser ring is highlighted with the location of the maximum and minimum values marked by red green markers respectively. Graphs to the left of the image show how the average and maximum diameter measurements vary with depth. The uppermost plot shows both these data on a moving x-axis while the lower plot shows all the average diameter data.

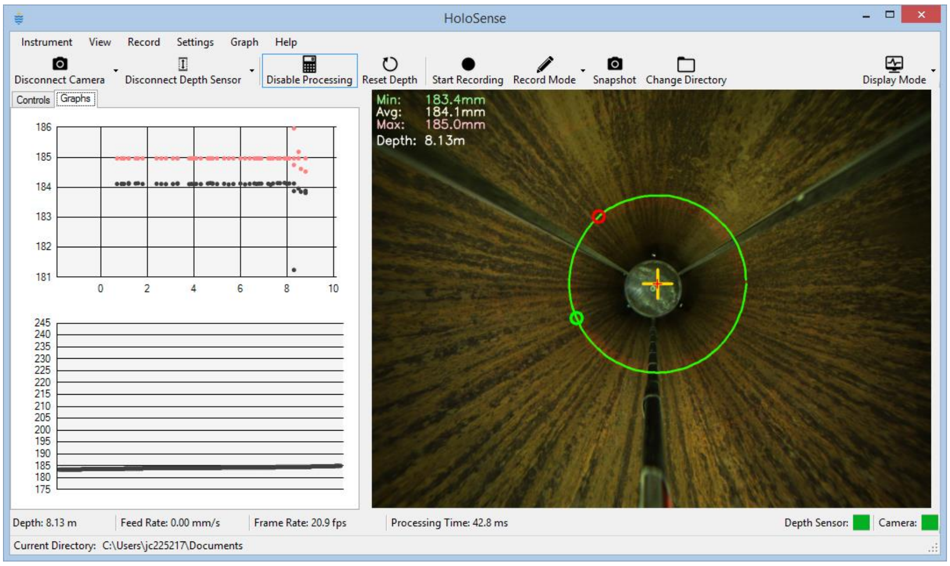


Figure 5 HoloSense software in use showing overlay and moving plots

When performing a pipe inspection, both the raw and processed video is stored for future reference. The software also allows for snapshots to be taken of any significant area of wear. Figures 6, 7 and 8 show some of the more interesting wear patterns and phenomena seen during the 2016 inspections. These images were collected with earlier versions of HoloSense with older cameras and different lighting configurations which explain the poorer image quality when compared to the color images shown previously.

One thing to note is that wear tends to be highly asymmetrical. The typical wear pattern consists of longitudinal gouges approximately 0.5~1 m long concentrated on one side of the pipe. This gouging out of the pipe wall begins with the formation of small grooves as seen in Figure 6 which continue to deepen with use and eventually lead to pipe failure as shown in Figure 8.

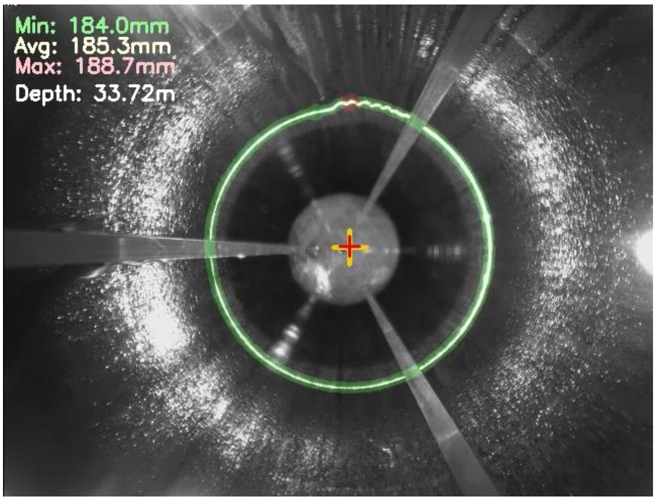


Figure 6 Early signs of wear

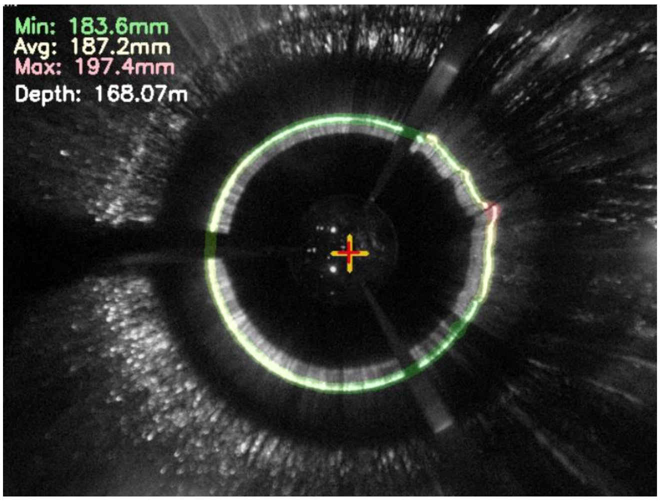


Figure 7 Progression of wear in paste pipe

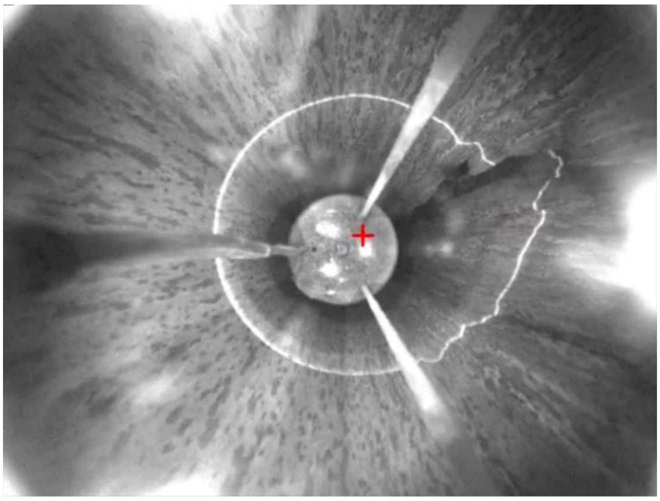


Figure 8 Failure of borehole pipe

4 Borehole axial measurements

4.1 Borehole pipe 1

Borehole pipe 1 has not been used since February 2015 due to a failure and as such we have not seen any change in wear in this time. Nonetheless it is still interesting to look at where and how the pipe has failed.

Figure 9 shows diameter measurements taken for Borehole Pipe 1 during the first inspection in December 2015. Red data points represent the maximum diameter recorded for a given depth while black data points represent the average diameter. In general the maximum diameter is roughly 2 mm greater than the average diameter. In areas of high wear however, the maximum diameter may be as much as 12 mm greater than the average.

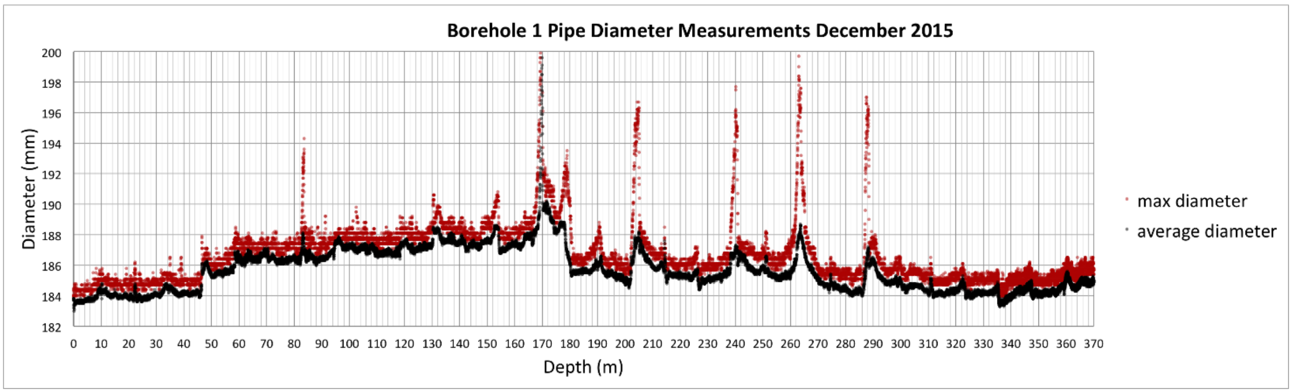


Figure 9 Wear in borehole pipe 1

The pipe has failed at 169 m (see Figure 8) and six other major areas of wear were identified at depths of 83 m, 179 m, 203 m, 239 m, 263 m and 287 m. A number of smaller areas of wear were also noted.

4.2 Borehole pipe 2

The pipe in borehole 2 (Figure 10) shows similar localized wear patterns as borehole 1. At one location, 168 m below the surface, the wall of the pipe in some spots was worn down to a thickness of approximately 5 mm from the nominal thickness of 18.26 mm. As a result of the very high wear measured the entire borehole pipe was subsequently replaced.

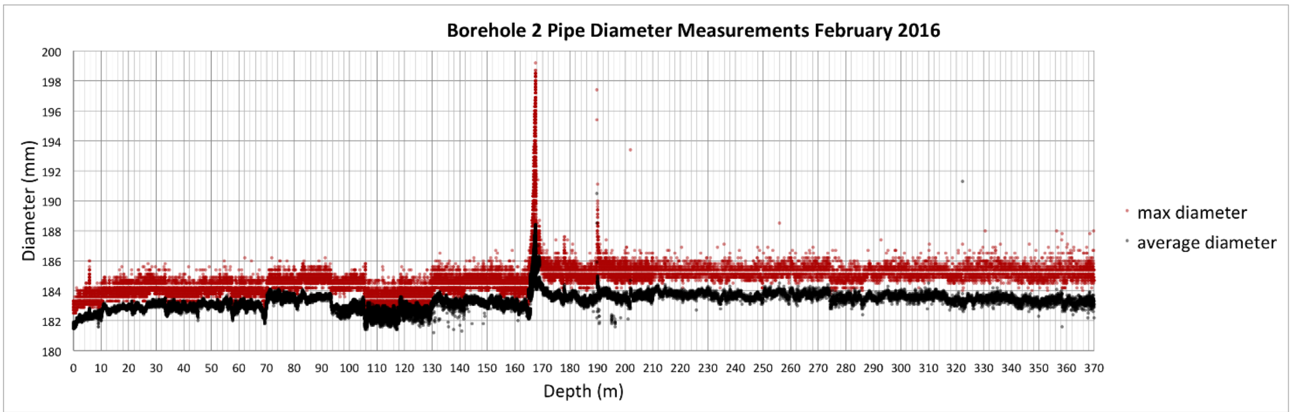


Figure 10 Wear in borehole pipe 2 measured in February 2016

Figures 11 and 12 show average and maximum diameter measurements of borehole pipe 2 taken in May and July of 2016, respectively. The diameter measurements remained quite stable during this period. According to Tanami Operations this may have been a result of an altered paste mix and prudent plant operation in that period. The striping seen in these plots represents the maximum resolution for a single reading. When these values are averaged over the entire circumference of the pipe a much higher effective resolution is achieved.

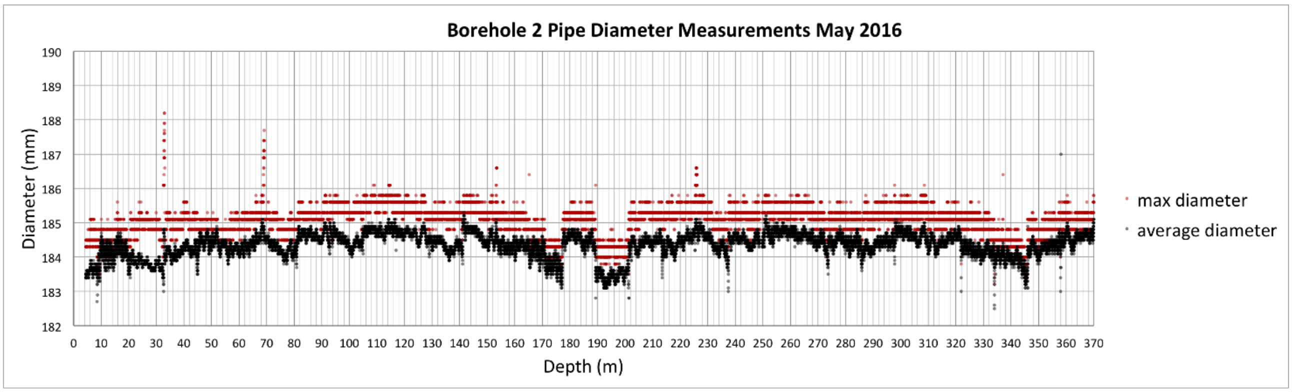


Figure 11 Wear in borehole pipe 2 measured May 2016

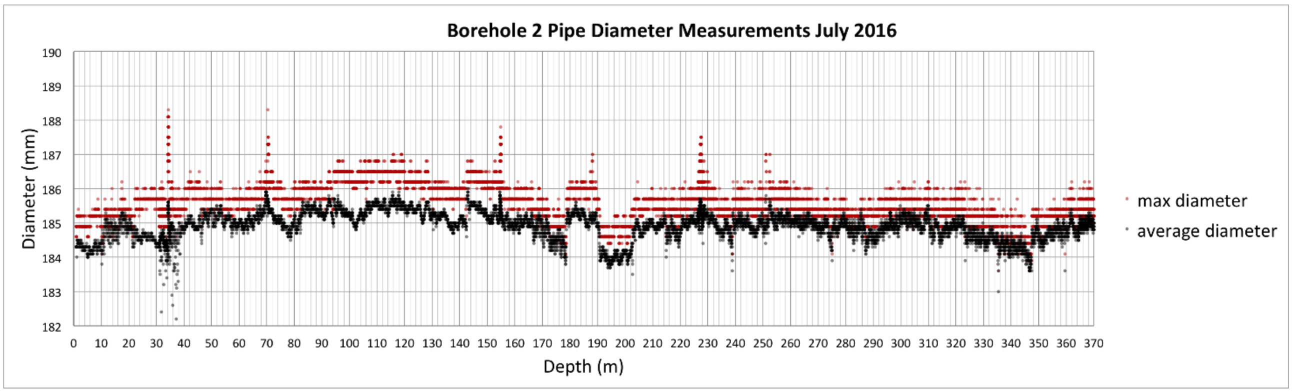


Figure 12 Wear in borehole pipe 2 measured July 2016

4.3 Calculating wear measurements

Using the diameter measurements and the nominal diameter of the pipe a wear measurement is calculated:

$$\text{Wear} = \text{Diameter Measurement} - \text{Nominal Diameter} \quad (1)$$

This measurement is used to give an indication of the amount of wear that is seen. However, there are two caveats:

- The nominal diameter may change slightly between pipe sections.
- The wear is assumed to be one sided. If there has been some wear on the opposite side, then the wear measurement will be inflated by this amount. Figure 13 shows the calculated double-sided wear for borehole pipe 2 as measured in May 2016. The mean wear and standard deviations of the data-set are also marked on the plot.

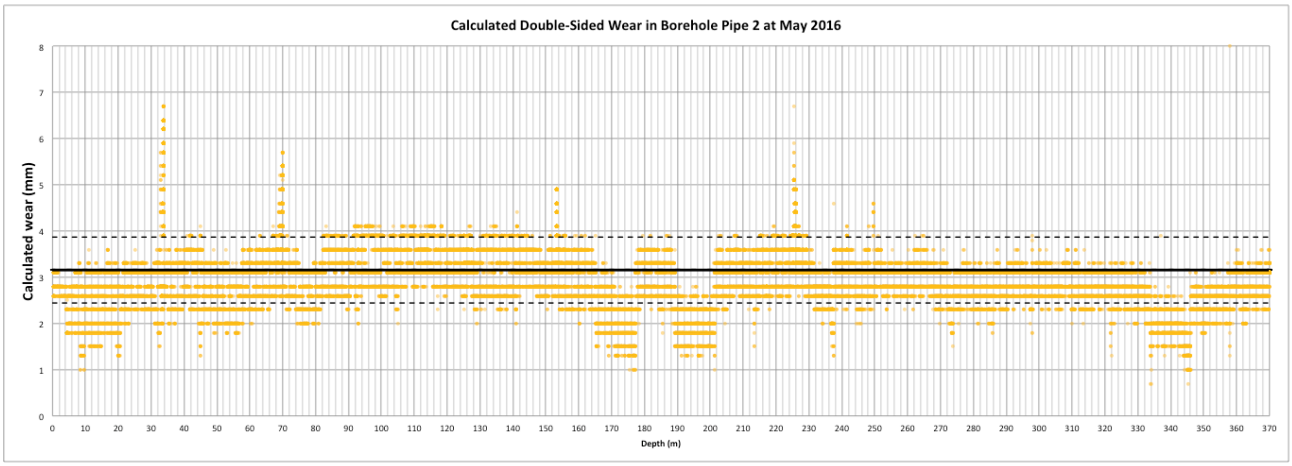
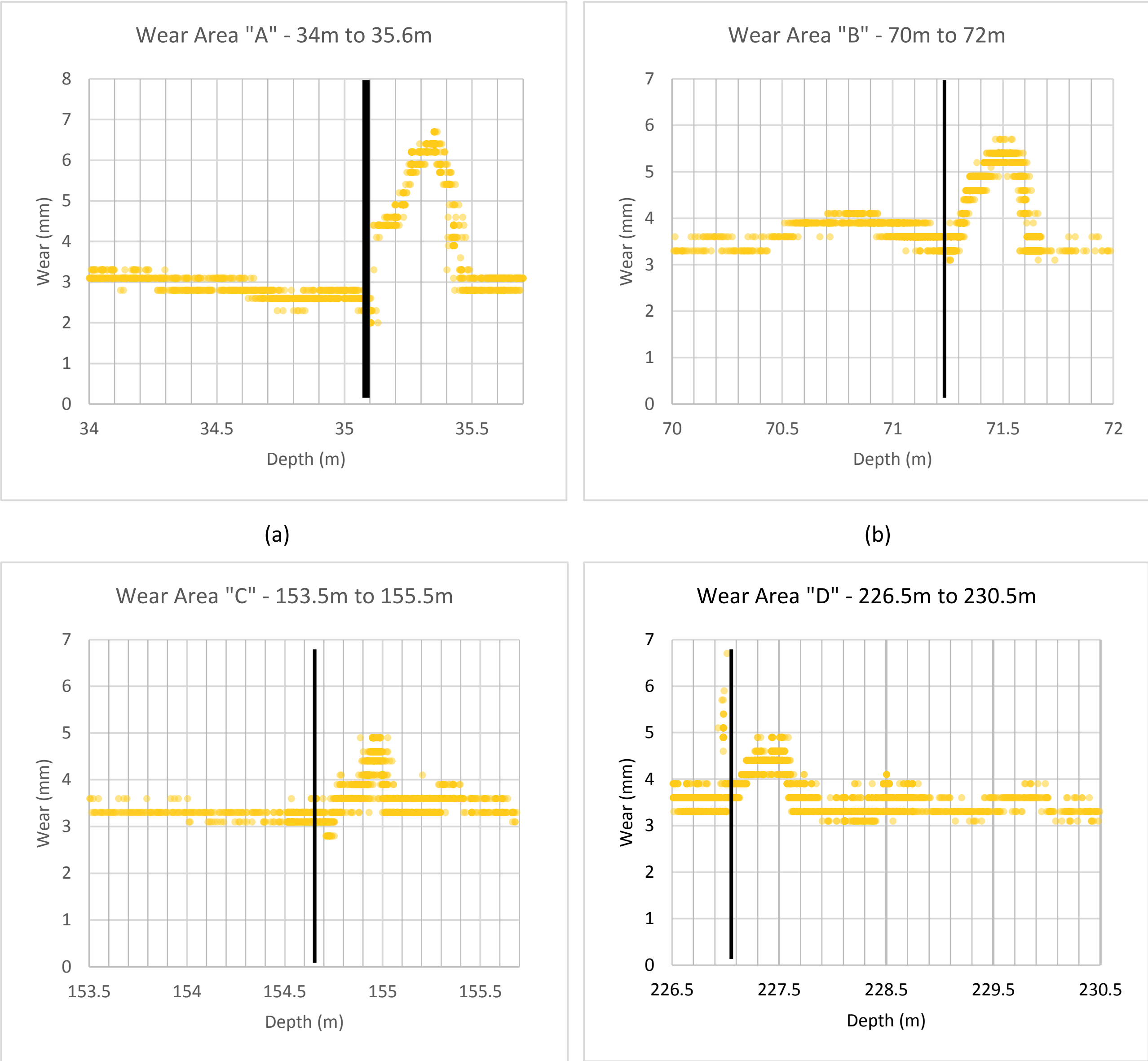


Figure 13 Calculated double-sided wear in borehole pipe 2 at May 2016 – full black line represents the mean wear for the entire pipe and dotted black lines represent ± one standard deviation from the mean

5 Discussion

The first thing to note from the inspection results in the previous section is that the wear of steel paste pipes at Tanami is localized. Looking at Figure 13 for example, it is clear that the areas of high wear cover just a few meters of the entire 370 m length of pipe. It is not desirable to replace hundreds of meters of good steel pipe for the sake a few meters of worn pipe. By developing a greater understanding of how this wear is caused, it is possible that measures may be taken to minimize it either by modifying the pipe design, changing the paste recipe, or alternatively by early intervention.

Of particular interest is the proximity of areas of high wear to the welded joints. Almost exclusively, the typical one-sided gouging out of the steel pipe occurs immediately below welded joints. Figure 14(a), (b), (c) and (d) show wear in mm calculated using Equation 1, against depth for four areas of increased wear in borehole pipe 2 as identified during the May 2016 site visit. A vertical line on the plot marks the location of the welded joint. At present it is not known why wear concentrates in these regions but if conditions under which the wear occurs could be understood better, it is possible that modified operation of the paste pipe could be implemented thus extending the effective life.



(a) (b)

(c) (d)

Figure 14 Localized wear in borehole pipe 2

6 Conclusion

Borehole paste pipes perform a vital role in the paste fill process and represent a significant capital investment. A new optic instrument has been developed that can quickly give very accurate measurements of pipe wear. It has been shown that wear is very much asymmetrical and is generally concentrated just below the joints of welded pipes. Further pipe surveys, both at Tanami mine and at other mine sites, will help to build a more complete picture of the mechanisms that cause this wear. Solutions to this problem can then be engineered in order maximize the life of paste fill borehole pipes and postpone the costs associated with pipe replacement.

References

Belem, T. and Benzaazoua, M. 2008, 'Design and application of underground mine paste backfill technology', *Geotechnical and Geological Engineering*, vol. 26, pp. 147-174.

Bickerstaff, R., Vaughn, M., Stoker, G., Hassard, M. and Garrett, M. 2002, 'Review of sensor technologies for in-line inspection of natural gas pipelines', *Sandia National Laboratories.*

GoWell 2016, ‘Multi-finger caliper’, Available: http://www.gowellpetro.com/product/multi-finger-caliper-mfc.html.

Hundertmark, H.W. and Davey, A.E. 1981, 'Pipe inspection apparatus', Available: Google Patents.

Maxted, L., Sondex, L., and Hazel, P. 1995, 'Advances in multi-finger caliper technology and data acquisition', *Offshore Technology Conference.*

Yin, J., De Gyves, J.P. and Lu, M. 1994, 'In-place detection of internal and external corrosion for underground casing pipes', *Proceedings of the IEEE International Conference on Industrial Technology*, pp. 789-793.