CONDITION MONITORING OF FABRIC-REINFORCED CONVEYOR BELTING USING DIGITAL X-RAY IMAGING

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1. INTRODUCTION

Fabric-reinforced conveyor belting is widely used for the transportation of various products (e.g. coal and ash in power stations). The ability to perform non-destructive condition monitoring of these belts would be beneficial to improve the reliability and availability of these belt transport systems.

For numerous years, X-ray technology has been successfully employed for imaging defects in the cords of steelcord-reinforced belting but sufficient contrast was not achievable for fabric-reinforced belting. The notion of imaging fabric belting using X-rays was previously thought not to be possible.

In 2003, tests were conducted by the Applied Physics Group (APG) of the University of KwaZulu-Natal (Durban) to determine the feasibility of using Digital X-ray Imaging (DiXI) for condition monitoring of fabric-reinforced conveyor belting. The approach was to use low-energy X-rays with sensitive, high-resolution digital X-ray cameras. APG evaluated various X-ray sources and cameras, and used readily-available off-the-shelf technology. A laboratory rig containing belt samples attached to a rotating drum was used to simulate the linear motion of the conveyor belt.

The investigation was successful, and was comprehensive enough to provide sufficient knowledge for the design, manufacture and implementation of a prototype system. Comprehensive tests conducted both in the laboratory and in on-site conditions have proven the suitability of DiXI to perform condition monitoring of conveyor belting. The internal structure of fabric-reinforced conveyor belting could be viewed with sufficient image contrast at belt speeds of up to 6 m/s.

During 2004, Advanced Imaging Technologies (AIT) was contracted by Eskom Enterprises TSI to build a prototype X-ray system for scanning fabric-reinforced belting. Several surveys of belts were carried out by AIT using the DiXI system at two Eskom power stations. Some results from these surveys are presented here.

2. DESCRIPTION OF THE DIXI SYSTEM

DiXI consists of an X-ray tube, HV generator, water cooler, digital X-ray camera, a lightweight aluminium frame to translate the X-ray tube and camera across the belt width, and a capture and analysis computer. The system requires a 220 VAC, 20 A power supply at the survey site.

All equipment can be easily transportable. **Figure 1** shows the equipment loaded in a Mercedes Vito van, which is parked within 15 m of the survey location. 20 m long cables connect to the X-ray camera and the tube, which are mounted on a translation rig either side of the conveyor belt.

Each survey can be divided into four processes: (1) Equipment Set-up, (2) Data Capture, (3) Data Analysis, (4) Reporting. The equipment setup usually takes about an hour.

Figure 1: The X-ray survey vehicle containing the DiXI system.

2.1 RADIATION SAFETY

A 20 m radius around the X-ray tube is cordoned off using barrier tape and radiation signs. All personnel wear radiation badges, and the survey area is constantly checked with a radiation monitor to ensure that radiation dose outside the barrier is always within the safety limits for public exposure.

2.2 DATA CAPTURE & ANALYSIS

Before data capture, the user inputs all belt and survey details into the capture station via a graphical user interface (GUI). All information is retained in an SQL database.

During the capture process, data is acquired from the X-ray camera in digital format, and streamed to the capture station.

Image processing algorithms are used to identify splices and defects. This is an automatic process but the software also provides the user with facilities to make any necessary manual changes. The splice and defect information are also stored in the database.

Once the analysis is complete, the survey report can be automatically generated with the list of splices, defects, positions and defect sizes.

Depending on the length of the belt, a full analysis of the data and the generation of a report can be completed by a single person in one day or less.

3. SOME NOTES ON THE INTERPRETATION OF DIGITAL X-RAY IMAGES

A digital X-ray image of a sample (for example, a belt) indicates how much of the X-rays were absorbed by the sample.

Darker regions of the image imply that more X-rays were absorbed by the corresponding area of the sample due to that region being thicker or composed of denser material. Debris on the belt (for example, residual coal dust) will appear as dark regions on the image. If the X-ray beam is blocked by steel supports, for example, the steel shows up as a very dark region (almost black) on the image.

Bright regions of the image indicate low X-ray absorption. This is important for identifying defects in conveyor belting since structurally weak regions of the belt appear as brighter regions in the image. Holes in belt, for example, will be intensely bright, almost white. Special attention should be paid to long, bright regions that span a major portion of the width of the belt, even if they are thin. These bright features indicate that one or more of the rubber layers have pulled apart, and hence these regions need to be urgently repaired.

4. TYPICAL RESULTS

The DiXI system was extensively tested at two sites: Majuba Power Station (2 x 1.4 km belts moving at 2 m/s) and Matimba Power Station (6 x 500 m belts moving at 2.6 m/s).

Figure 2 shows a compressed X-ray image of the full belt which is oriented vertically. The thin horizontal lines correspond to the location of the splices. The irregular tracking of the edges of the belt is accentuated by the compressed format of this belt image. However, it can be seen that often the presence of a splice produces a sudden transverse motion of the belt. Changes in belt compound can be seen as changes in the grey-level intensity between splices.

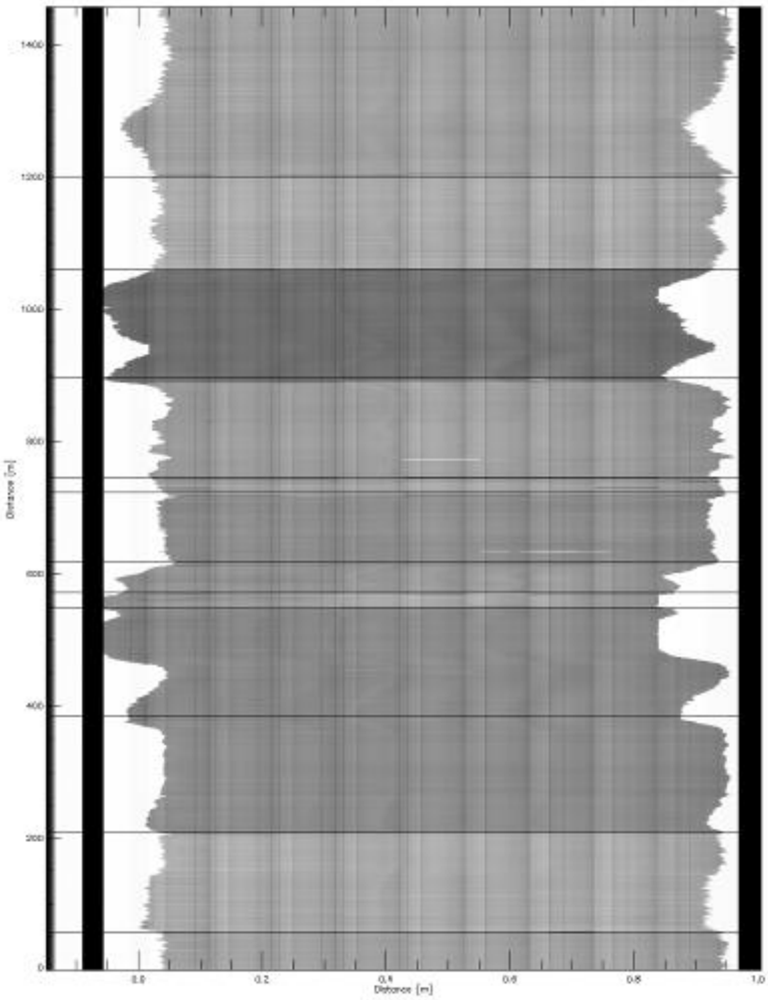


Figure 2: Full belt keogram. The splices are indicated by the black horizontal lines. The three dark wide vertical bands correspond to the steel beams on the conveyor belt support structure.

The results of the survey analysis can be represented in various table formats containing the positions of the splices and damages together with their images. However, it has also been found useful to represent the results in the form of a schematic as shown in **Figure 3**. The top and bottom panels show the belt edge tracking signature obtained directly from the X-ray data. The central region shows the longitudinal position of the detected splices and the damages relative to a reference splice.

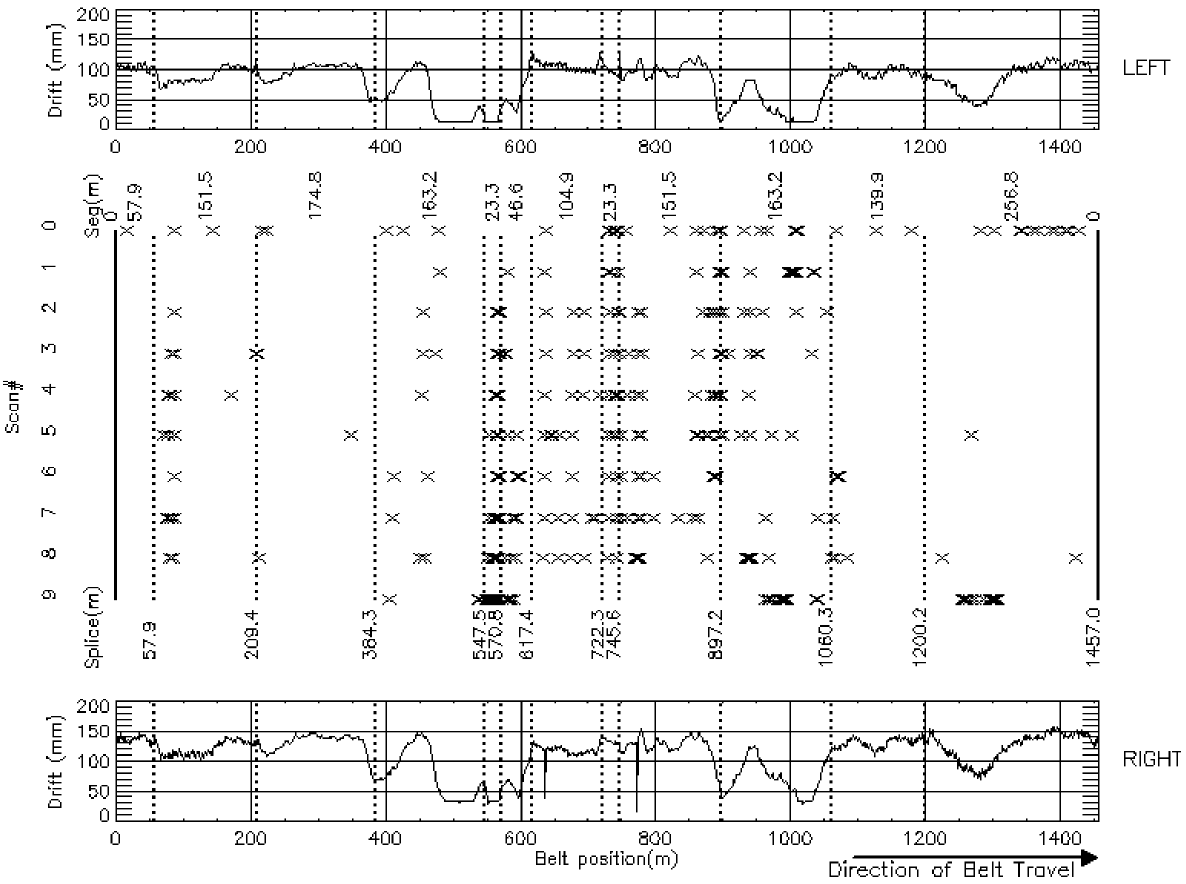


Figure 3: An example belt schematic after analysis. The left and right hand side edge tracking signatures are shown in the panels at the top and bottom, respectively. The central region shows the longitudinal positions of the splices (vertical dashed lines) and the positions of the damages (crosses).

In order to determine to what extent features in the X-ray images corresponded to actual visible features on the top and bottom covers, following the X-ray survey, a careful walk through of the full length of the belt was undertaken. In all cases even fairly subtle damages, press marks, stamps and splices were visible. In addition, as expected, sometimes the internal weave structure in the interior of the belt was visible in the X-ray images but not by viewing from the outside.

4.1.1 Splices

Typical X-ray images of splices are shown below in **Figure 4**. The splices are indicated by the darkened regions extending across the belt width (from the top to the bottom of the image).

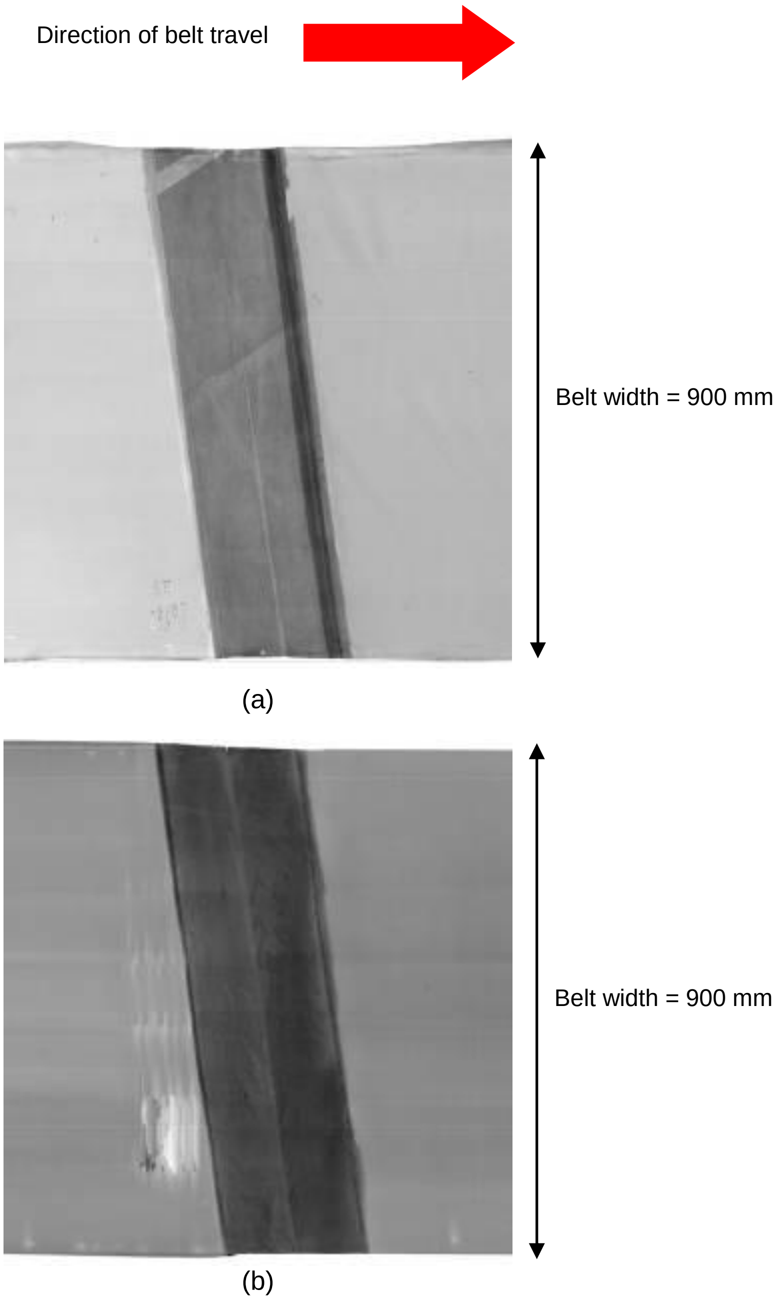
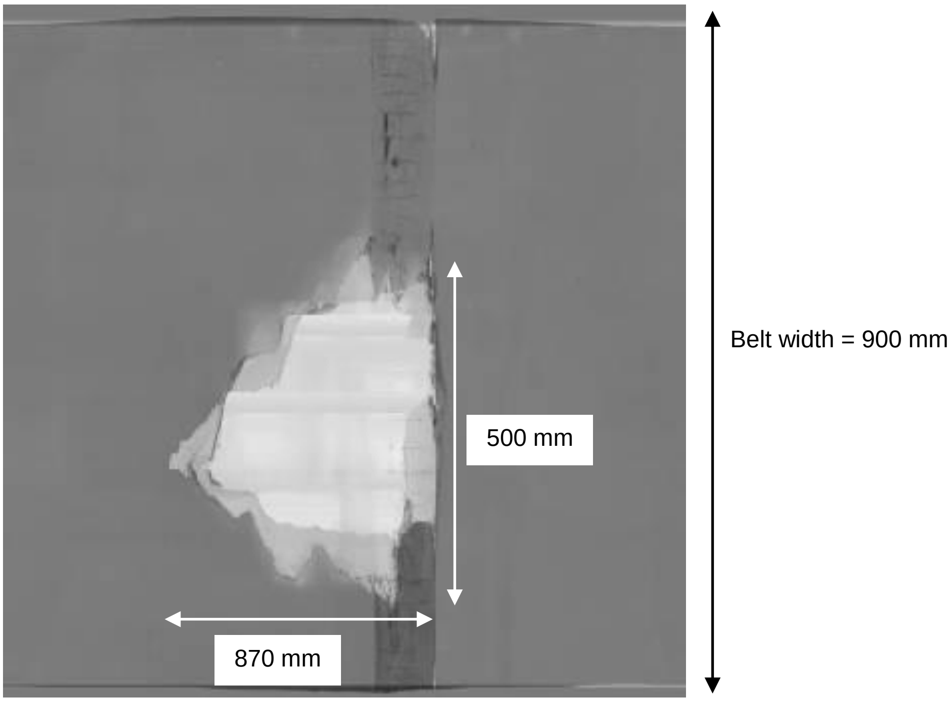


Figure 4: Examples of X-ray images of splices.

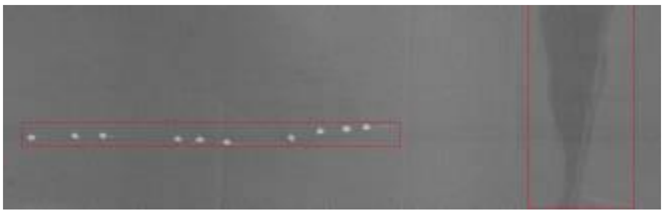
4.1.2 Damages



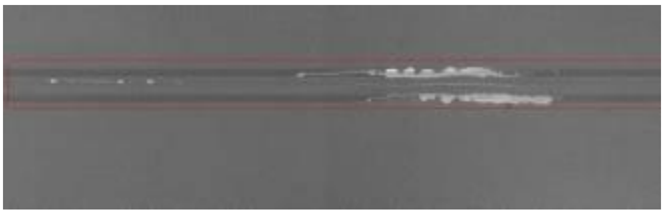
Large hole

Vertical tear

An edge damage



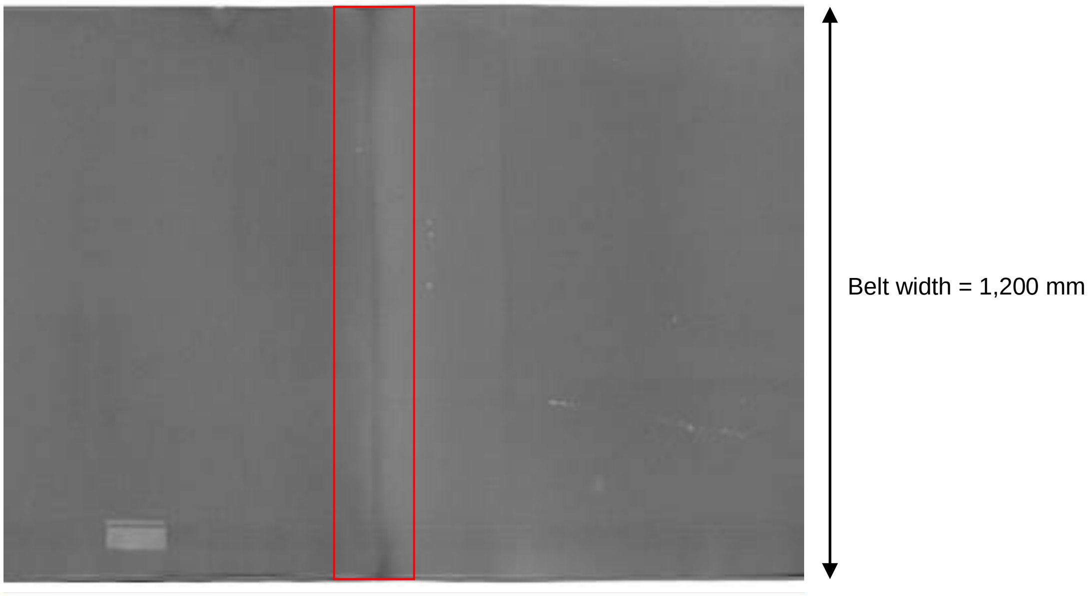
Small holes



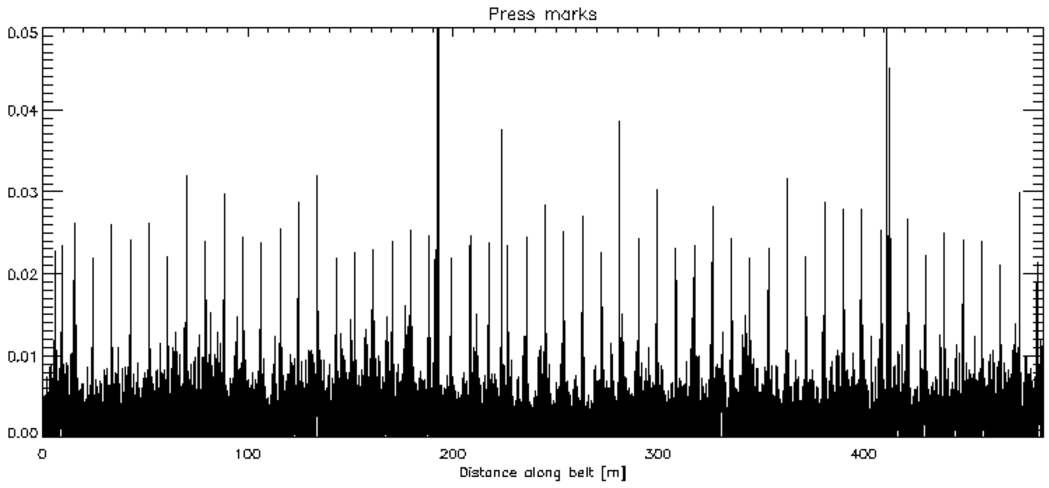
Folds in the rubber

Figure 5: X-ray images of various damages found during the test surveys.

4.1.3 Press Marks



(a)



(b)

Figure 6: (a) An X-ray image of a press mark, that is imprinted during the belt manufacturing process, contained within the red rectangle. (b) Positions are shown of the press marks and splices for the entire length of belt using a damage detection algorithm. The press marks are indicated by the periodic short peaks, and the two splices of the belt by the tall peaks. The press marks occur every 9 metres.

5. FUTURE WORK

The DiXI software will be expanded to include the identification of defects in steelcord-reinforced conveyor belting (e.g. variable cord spacing, missing and damaged cords).

6. CONCLUSION

DiXI is fully capable of detecting damages in fabric-reinforced conveyor belting. The downside of the system is the high capital cost of the equipment (about R 1.5M), which means that it is not practical for it to be installed permanently on a single belt. Rather, it is best suited to a survey model, where the entire system is packaged in a trailer and then transported between conveyor belt sites for periodic surveys. With the reduction in data interpretation and report generation time made possible by the intelligent software the service can be rendered cost effectively. Although this paper has focused on the use of DiXI for fabric cord belts, the same hardware can also be used for steelcord-reinforced belts.

7. ACKNOWLEDGEMENTS

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Paper to be presented by MJ Alport.

8.1 Curriculum Vitae of JH Fourie

Qualifications:

- B. Eng. (Mechanical) 1992 , University of Pretoria.

Experience:

- Senior Engineer, Auxiliary and Chemical Plant, Capital Expansion Department, Eskom Holdings.
- Since 1993 involved in various Bulk Solids Handling related research, test, investigation, simulation and design projects in Eskom.

8.2 Curriculum Vitae of MJ Alport

Qualifications:

- BSc (Hons) (Physics) 1974, University of Natal, Durban.
- MSc (Physics) 1975-1977, University of Natal, Durban.
- PhD (Plasma Physics) 1977-1981, University of Iowa (USA).

Experience:

- 1978 → 2000: Visiting scientist at Laboratoire de Mécanique des Fluides, Grenoble, France; University of Groningen, Nuclear Physics Department, KVI; Dept. of Physics, West Virginia University, Morgantown; Dept. of Nuclear Engineering and Engineering Physics, University of Wisconsin, Madison, Wisconsin; Laboratory for Plasma and Fusion Energy Studies, University of Maryland, College Park, MD; Dept. of Physics and Astronomy, University of Iowa, Iowa City, Iowa.
- 1981 → present: Associate Professor and Head of the Applied Physics Group. School of Physics, University of KwaZulu-Natal, Durban.
- 2004: Founder and MD of Advanced Imaging Technologies (Pty) Ltd.

8.3 Curriculum Vitae of JF Basson

Qualifications:

- BSc (Physics, Mathematics) 1998, University of Natal, Durban.
- BSc (Hons) (Physics) 1999, University of Natal, Durban.
- MSc (Physics) 2001, University of Natal, Durban.
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Experience:

- March 2003 → December 2003: Consulting Physicist for the Applied Physics Group at the University of Natal.
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8.4 Curriculum Vitae of T Padayachee

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- MSc (Applied Physics) 2001, University of Natal, Durban.
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Experience:

- 1995 → 1997: Vacation work at DebTech in Johannesburg, mainly in the field of X-ray and Gamma Spectroscopy.
- January 1998 → December 1999: Assistant Research Officer at DebTech. Project experience included X- and Gamma-ray Spectroscopy, X-ray Computed Tomography, X-ray Digital Radiography, Neutron Activation Analysis, X-ray Fluorescence and Infrared Reflectance Spectroscopy.
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