This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2021-10993C

Cyclic Bend Over Sheave Performance of A Steel Tension Member Belt for Wave Energy Conversion

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14th European Wave and Tidal Energy Conference (EWTEC 2021)

5 – 9 September 2021

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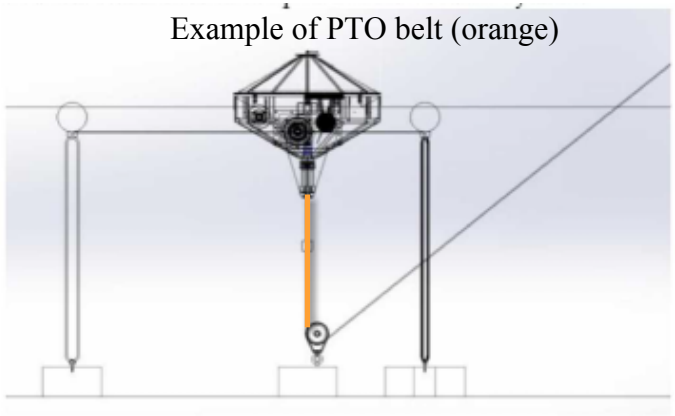
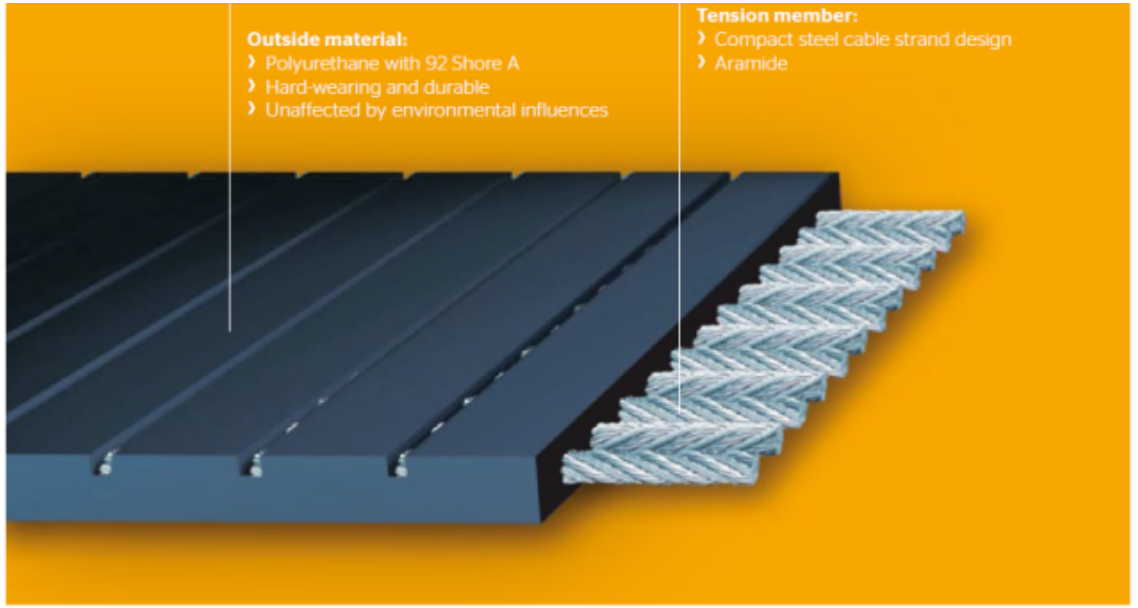
Belt for WEC PTO Mooring





- Winch-type PTOs can impose millions of bending cycles on the belt or rope element every year, which may lead to a failure mode known as Cyclic Bend Over Sheave, or “CBOS”

- No commercially available rope technology that can economically achieve more than 200,000 CBOS cycles [1].

[1] G. Maassen and R. Chou, High performance synthetic ropes for wave and tidal PTO applications. Proceedings of the Asian Wave and Tidal Energy Conference 2018, Taipei, Taiwan.

PTO Belt – AquaHarmonics WEC

AquaHarmonics PTO testing (with belt), at Sandia Wave Energy Power Take-Off (SWEPT) Lab

SWEPTLAB
SANDIA WAVE ENERGY POWER TAKE-OFF

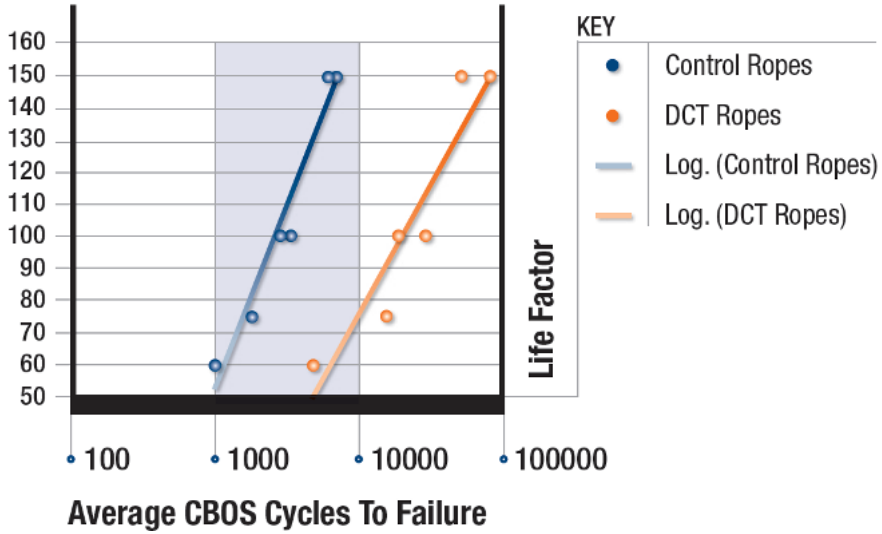
Study Objective

- Twist/Fleet angle can be an issue for belts – difficult to maintain even tension across the width of the belt

- Belt sections experienced:
  - No bend cycled
  - 1 bend per cycle
  - 2 bends per cycle

- Using belts instead of ropes for winching elements could improve CBOS performance due to having a smaller thickness that undergoes bending

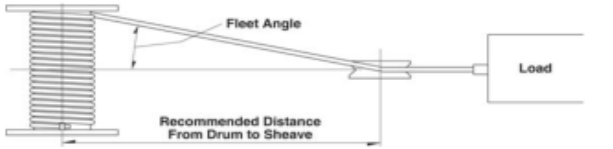
- This study sought to quantify the CBOS performance of a belt constructed of steel tension members in a polyurethane matrix containing longitudinal profiles



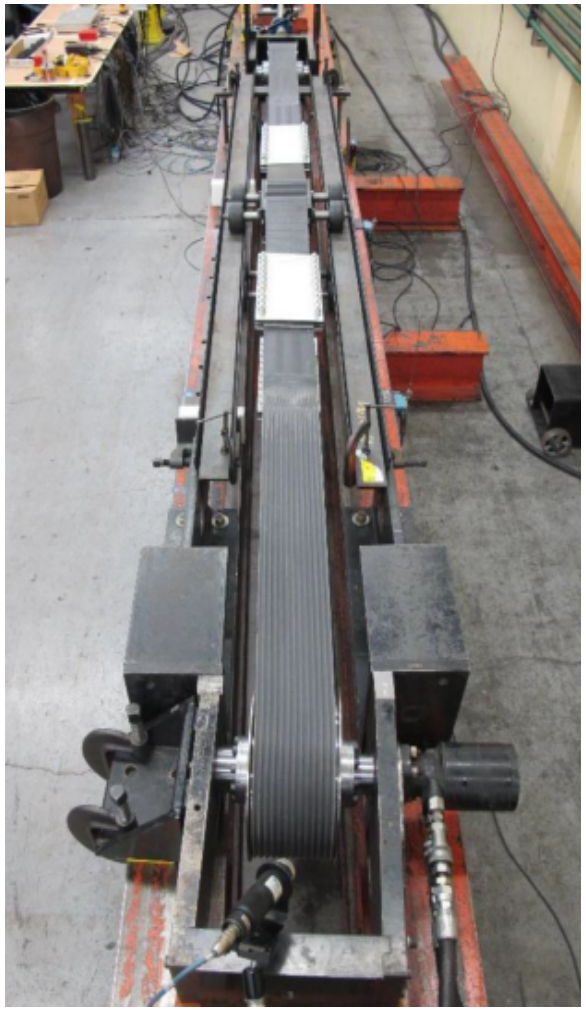
$$LF = SF \times \frac{D}{d} = \frac{MBL}{T} \times \frac{D}{d}$$

LF = life factors
SF = safety factor
MBL = minimum breaking load
T = rope tension (MBL)
D/d = ratio between the sheave diameter the rope is bent around to the rope's diameter.

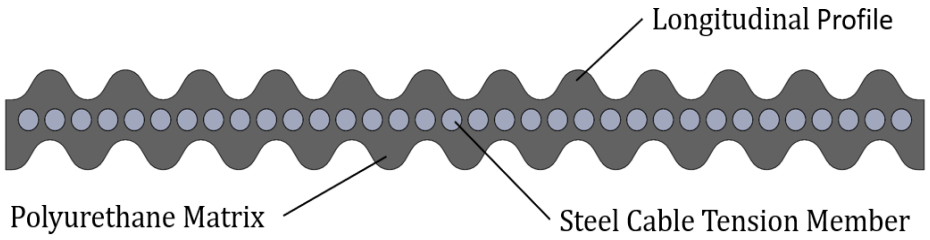
Test Rig

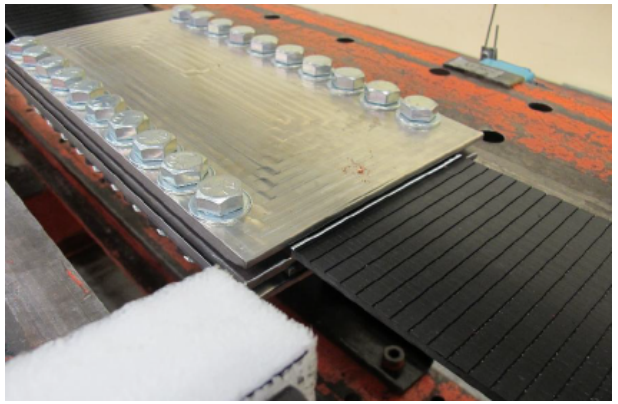


Fleet angle definition (www.thern.com)



Test Set Up





Belt termination

Drive drum and IR temperature sensor

Tensioning drum clevis assembly attached to load cell and hydraulic tensioning cylinder

Belt samples attached to termination support trolleys.

Test Video

Test Video

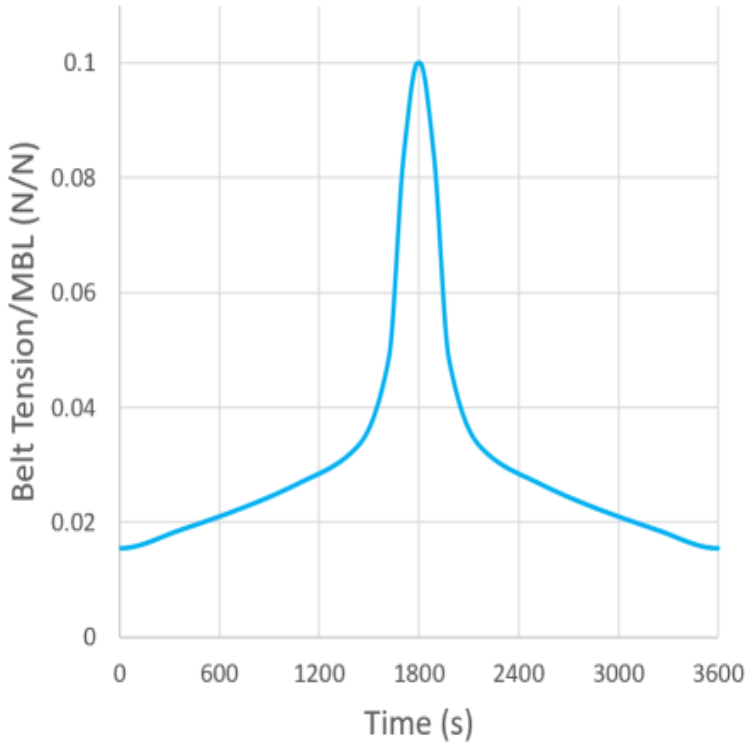
Test Cases

CHRONOLOGICAL BENDING TESTS

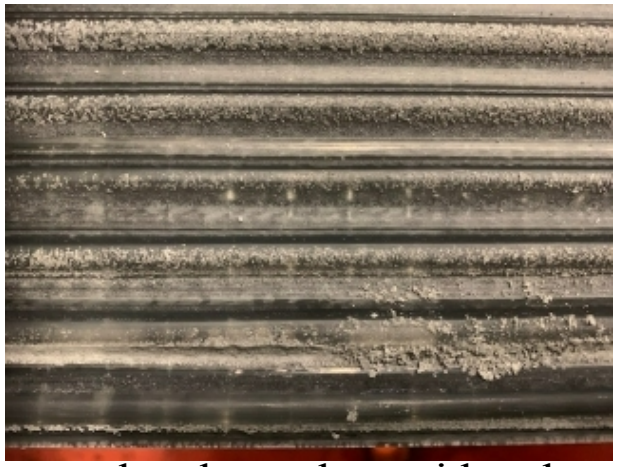
Cycle Block	Fleet Angle (°)	Normalized Tension (N/N)	Machine Cycles	Cumulative Machine Cycles
1	3.0	0.024	400	400
2	3.0	0.016	26	426
3	3.0	0.016	36	462
4	0.0	Profile	250,000	250,462
5	1.0	Profile	46,953	297,415
6	0.0	Profile	176,497	473,912
7	0.5	Profile	123,550	597,462
8	1.0	0.089	153,500	750,962
9	2.0	0.016-0.156	37	750,999
10	1.5	0.016-0.156	58	751,057
11	1.5	0.138	37,655	788,712
12	1.5	0.138-0.016	50	788,762
13	2.0	0.016-0.138	95	788,857
14	2.0	0.089	58,755	847,612

CUMULATIVE BENDING BY FLEET ANGLE

Fleet Angle (°)	Tension (N/N)	Total Machine Cycles
0.0	Profile	426,497
0.5	Profile	123,550
1.0	Profile and 0.089	200,453
1.5	Various	37,763
2.0	Various	58,887
3.0	0.016 and 0.024	462

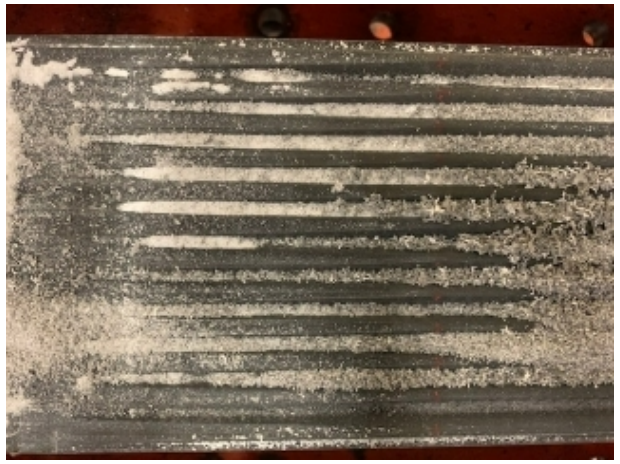


Results

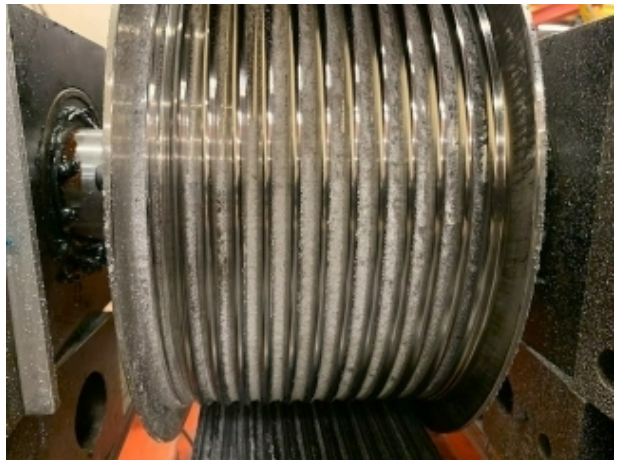


Accumulated powder residue thought to be worn polyurethane debris

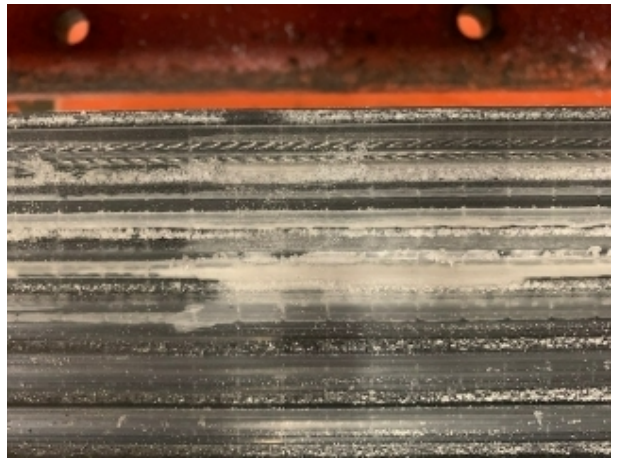
Drive belt wear in double bend zone after 750,962 cycles. Greatest wear on the near edge of the belt.



Belt wear residue at 847,612 machine cycles

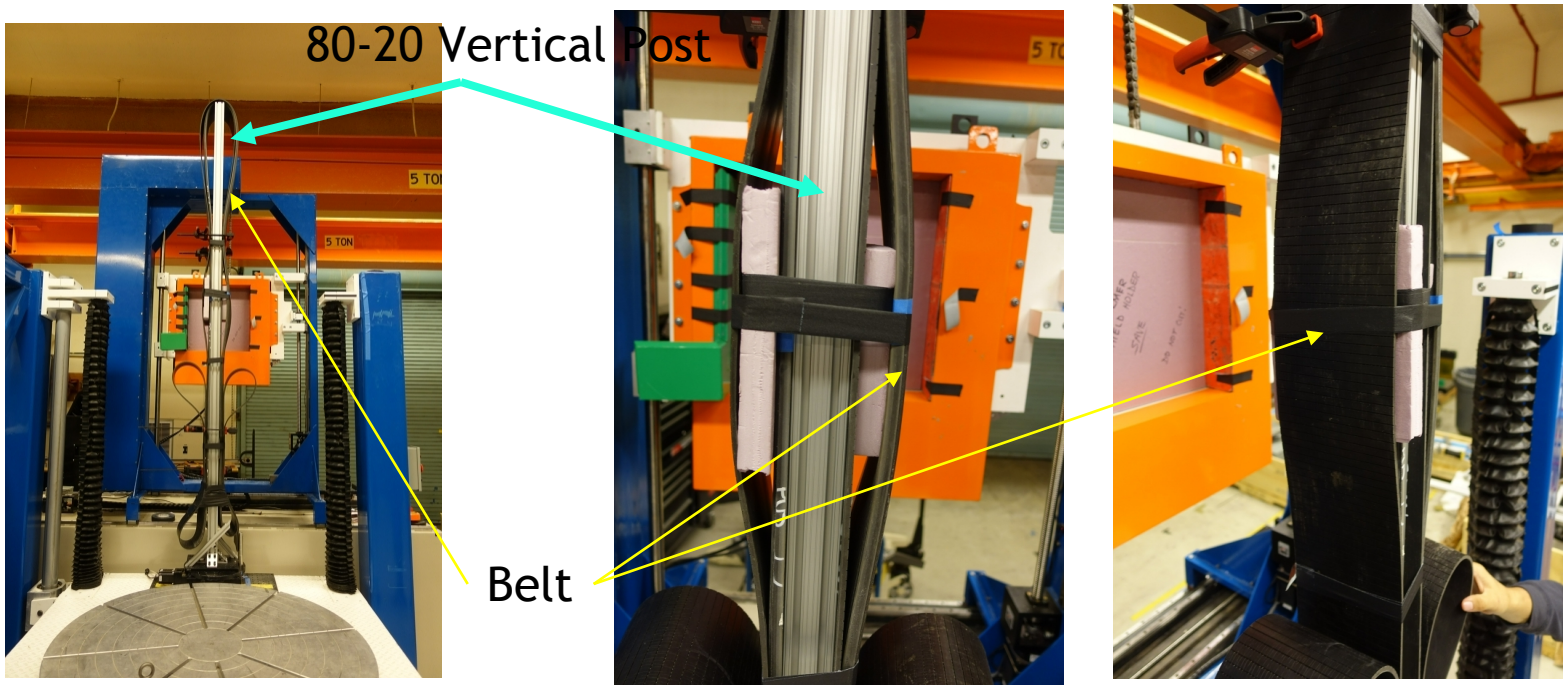


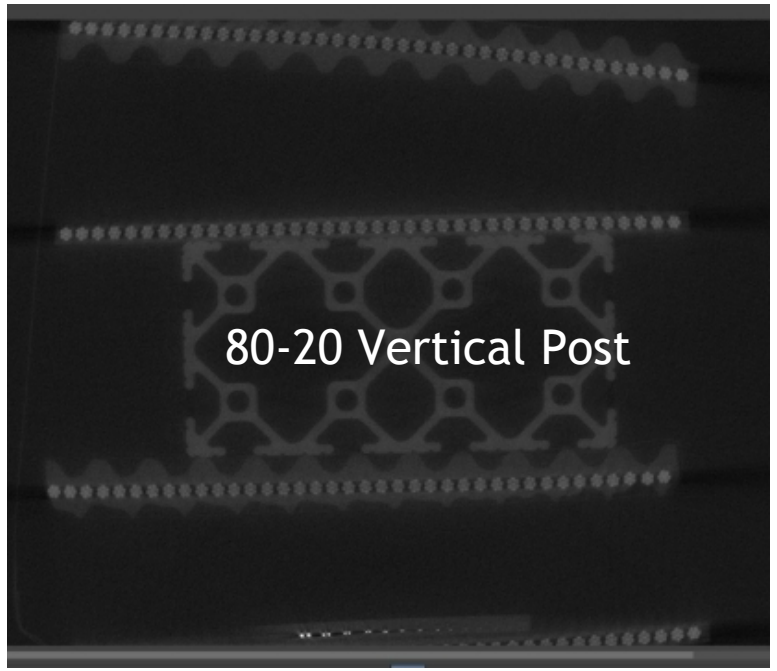
Belt wear debris in drum grooves at 847,612 machine cycles.



Exposed steel cables at 847,612 machine cycles

Post Mortem – Nondestructive Testing





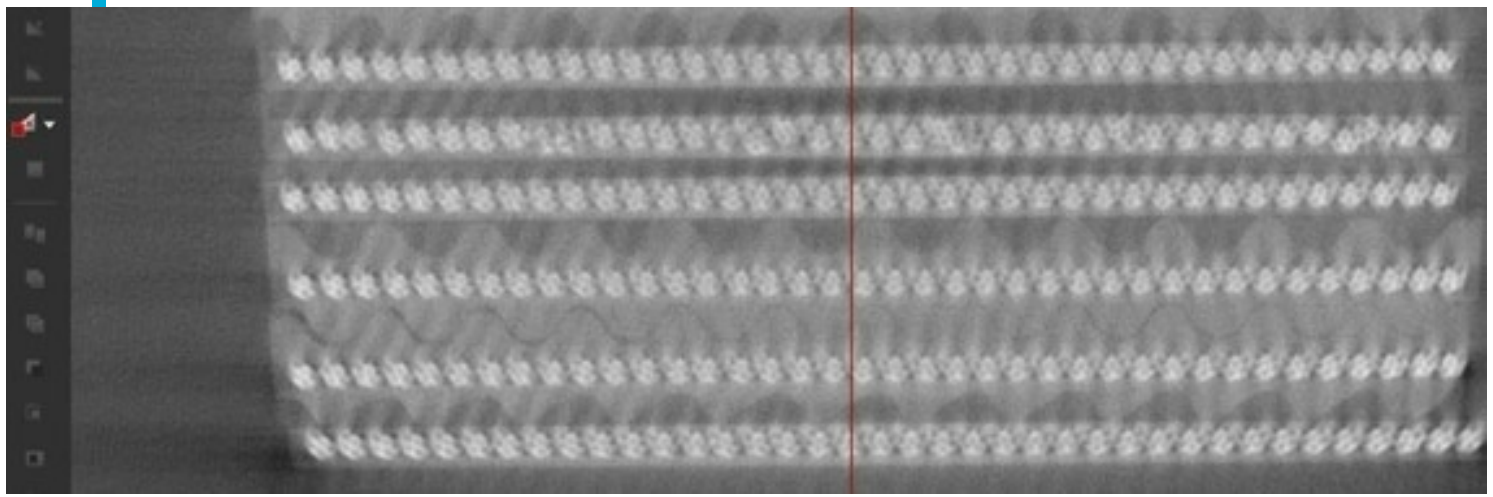
The belts were scanned using the below equipment and parameters:

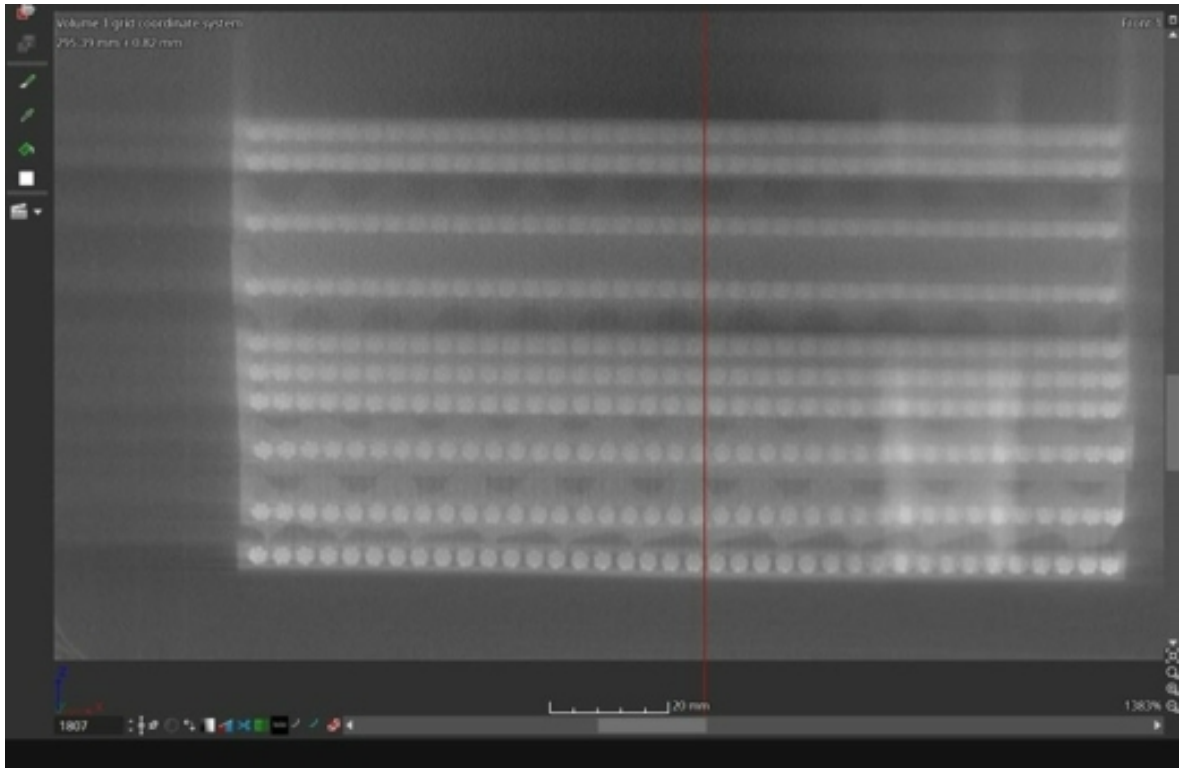
- Varex M9A Linear Accelerator in the 6 MeV Mode
- Perkin-Elmer 1611 AP Flat Panel Detector in 1 x 1 mode
- Multi Axis Galil Motion Control System
- North Star Imaging eFx DR Acquisition Software
- Volume Graphics Reconstruction and Analysis Software
- Image J Image Processing software for AVI production

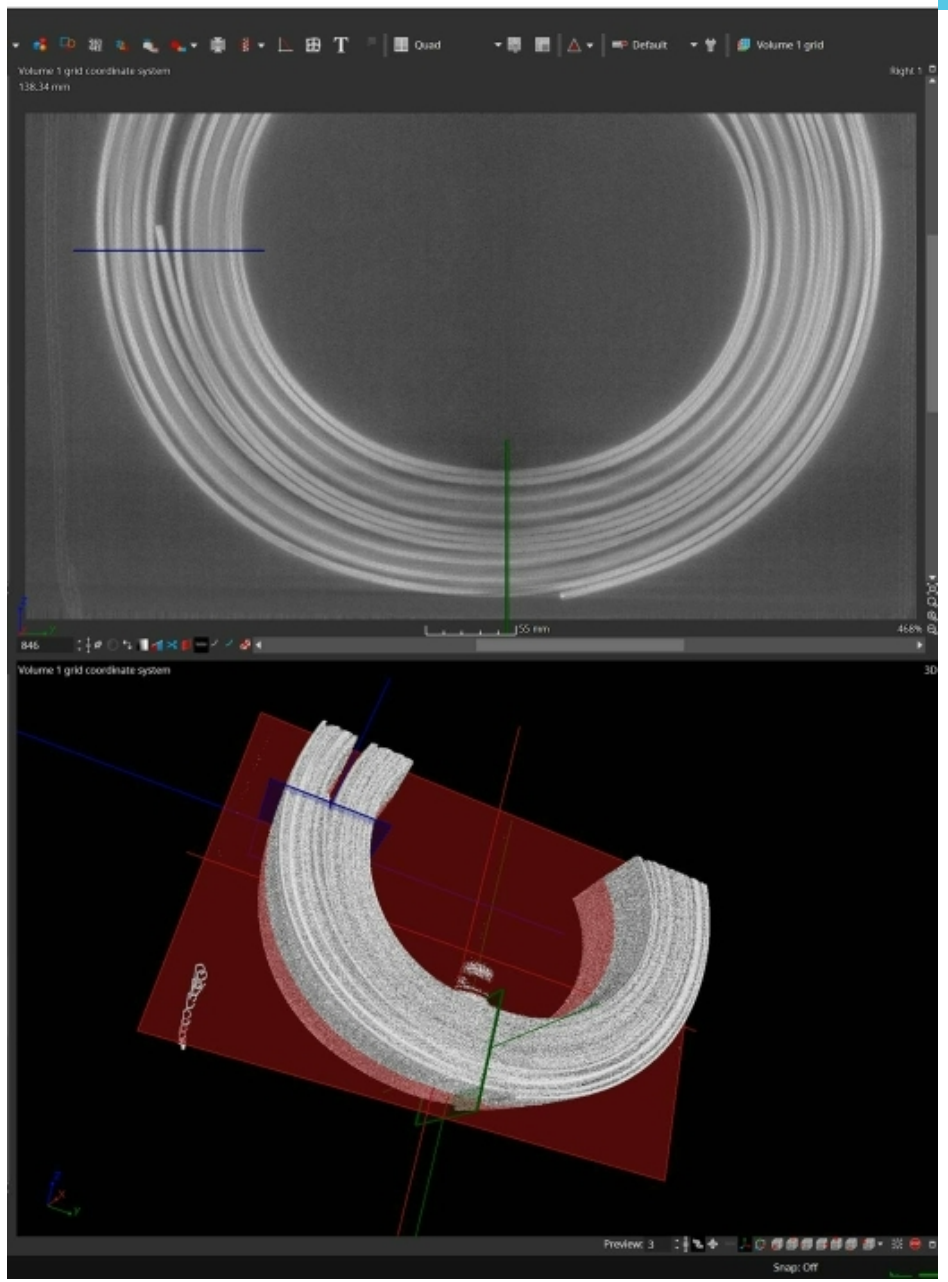
- Final Effective Pixel Size of 92 µm
- 1500 Projections
- 4 Frame Average
- 4 hours 12 min scan duration
- .5 Frames Per Second with a 50ms delay between steps

Acknowledgement: David Moore, Carl Jacques, Kyle Thompson, Sandia National Laboratories NDE & Model Validation

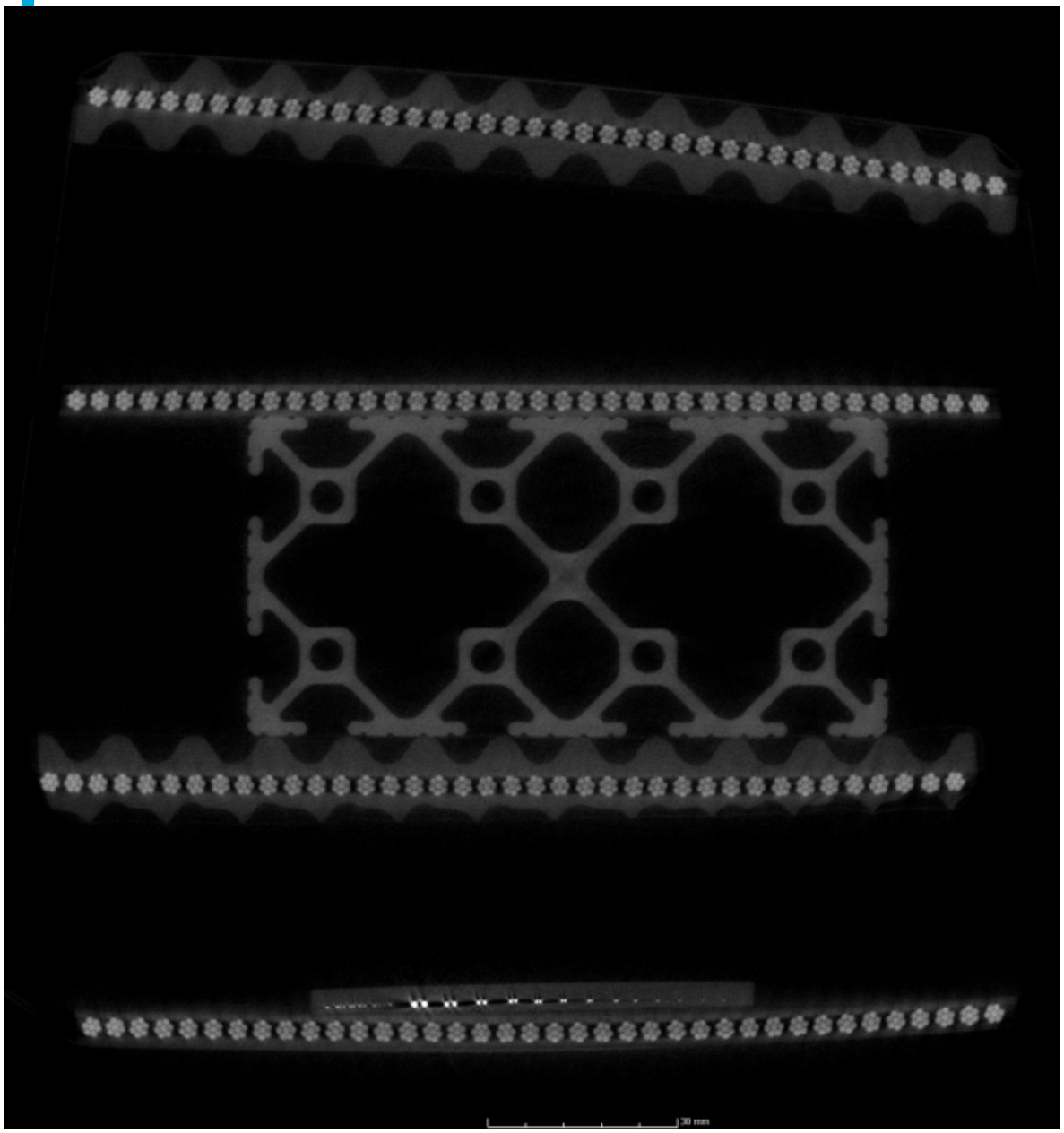
NDT Results

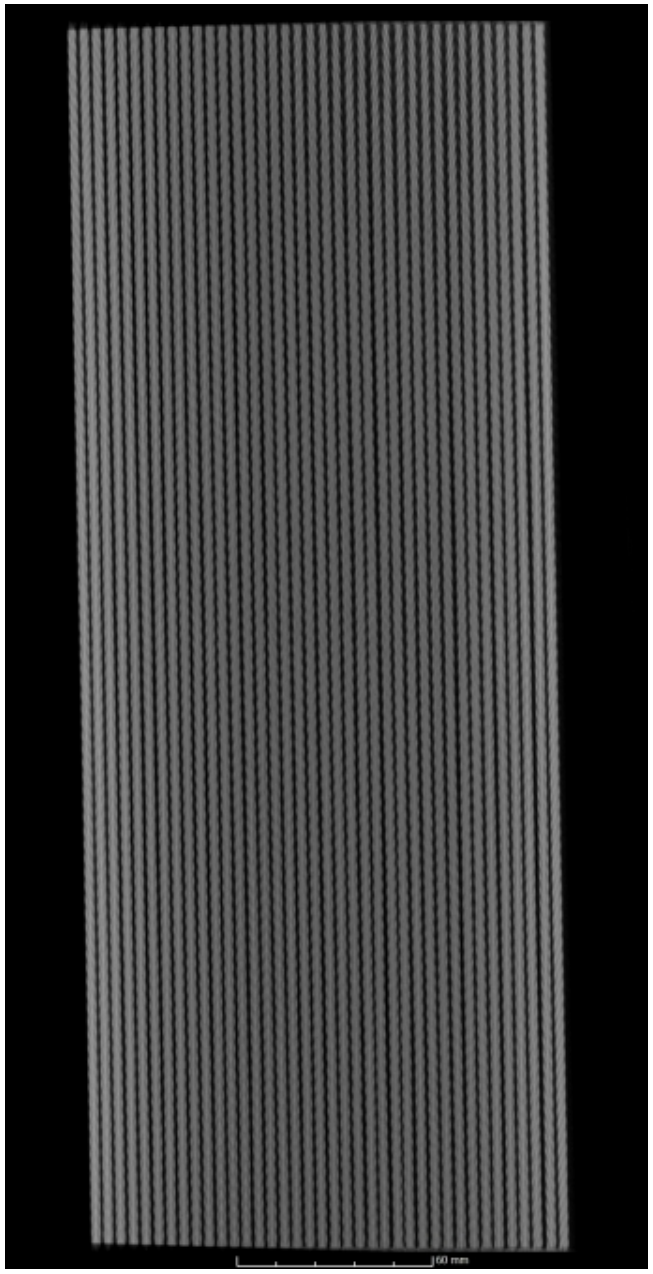






NDT Results





The overall quality of the scan provides the ability to evaluate the wire rope clearly.

Potential issues such as birdcaging, broken strands, and other defects could be observed if present.

Conclusions

- The belt sample on the tension drum endured all 847,612 cycles without failing or showing visible signs of wear.
- Wear of the belt polyurethane caused by fleet angle induced off-axis loads could ultimately determine component life.
- Even with the longitudinal profiles, the belt had difficulty maintaining engagement with the drum at fleet angles of 1 degree and larger.
- Tensions that are too low can lead to belt instability when fleet angles are present.

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