ESRF	**Experiment title:** Play it again – Recovering archived music from degraded analogue magnetic recordings using RIXS-MCD	**Experiment number**: HG-244
Beamline:	**Date of experiment**: from: 12/02/25 to: 17/02/25	**Date of report**: 21/02/2025
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Report:

Summary:

In this experiment, we aimed to increase the readout speed and measurable frequencies from historic magnetic analogue audio tapes utilising the von Hámos spectrometer and high photon flux available at ID20. Whilst the von Hámos was found to be detrimental to the readout speed, we implemented a novel dispersive detection scheme in the Rowland spectrometer arrangement that significantly sped up the readout process. By generating circularly polarised X-rays using the diamond phase plate and exploiting the X-ray magnetic circular dichroism (XMCD) effect, the orientation and strength of the magnetic domains within the tapes can be measured with 1s2p resonant inelastic X-ray spectroscopy (RIXS). We then defocused the analyser crystals to create an energy dispersion sufficient to resolve the XMCD peaks, increasing the readout speed by at least a factor 4 because switching the circular polarisation is no longer needed. We demonstrated readout of audio frequencies up to at least 11 kHz, which is limited by the beam focussing to 13 µm, with a clear route to improve this further with enhanced optics. We applied this approach to readout segments of heavily degraded tapes suffering from sticky-shed syndrome and extreme warping, demonstrating that this technique is promising for readout of historic magnetic recordings that will otherwise be lost.

Results:

After aligning the von Hámos spectrometer and measuring a RIXS XMCD map, we measured the signal from a tape recorded at 19.1 cm/s with a 795 Hz sine wave. The dichroic region of the spectrum is shown as a function of tape position in Fig. 1a and the corresponding extracted waveform in Fig. 1b. This required very long integration times per point (120s) due to the too large energy dispersion of the von Hámos spectrometer, which is detrimental for our purposes due to low photon efficiency in the narrow energy bandwidth around the Kα1 emission line. We therefore conclude that a von Hámos spectrometer is not a practical device for fast tape readout.

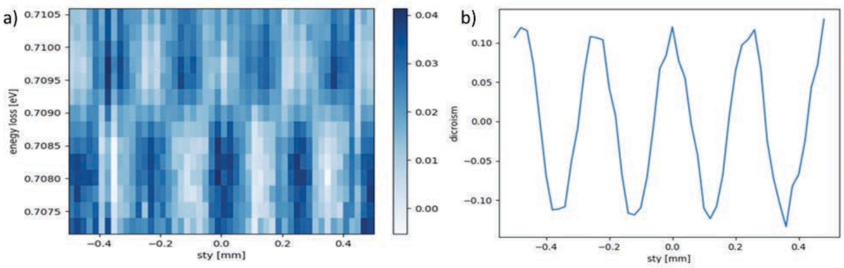

Figure 1: a) von Hamos energy dispersion across the XMCD energies scanned along a tape recorded with 795 Hz measured with 20 µm resolution and 120 s per point. b) extracted waveform from averaging along the dichroic dispersion at each point from (a).

Subsequently, we implemented an off-Rowland geometry on the Johann spectrometer, with the Rowland circle shrunk by 20 mm. This leads to a small energy dispersion (~3eV) sufficient to resolve the two dichroic peaks in the 1s2p RIXS-MCD plane. This was confirmed with a saturated tape by switching both the X-ray polarisation and magnetic field, and calculating the difference images from the scattering on the detector (Figs. 2a,b). This was then used to generate a mask to extract the dichroic contrast from other tapes with a single incident X-ray energy and polarisation. We demonstrated a significantly faster readout rate with this configuration and were able to measure a 1 kHz tone with less than 3s per point; over 40 times faster than with the von Hámos (Fig. 2c). These measurements were performed with a microfocussed 13×30 μm^2 beam and we demonstrated that we could succesfully measure audio frequencies up to at least 11kHz (Fig. 3).

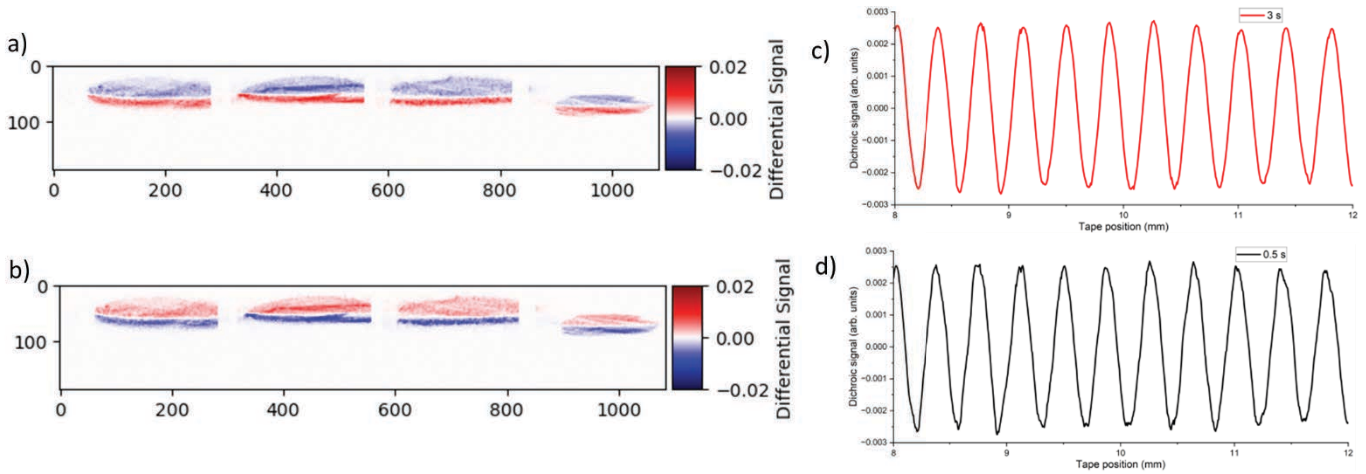

Figure 2: The difference in the detector images taken with opposite photon helicities with a saturated magnetic tape at 45deg to the incident beam and with a magnetic field applied (a) along the beam direction and (b) opposite the beam direction. This shows clearly the scattering regions most sensitive to opposite magnetizations. c,d) measured dichroic signal from a 1 kHz tape taken with 3 s (c) and 0.5 s (d) integration time per image. The signal to noise clearly improves with increased integration time but is sufficient to recover the signal with even 0.5s per point.

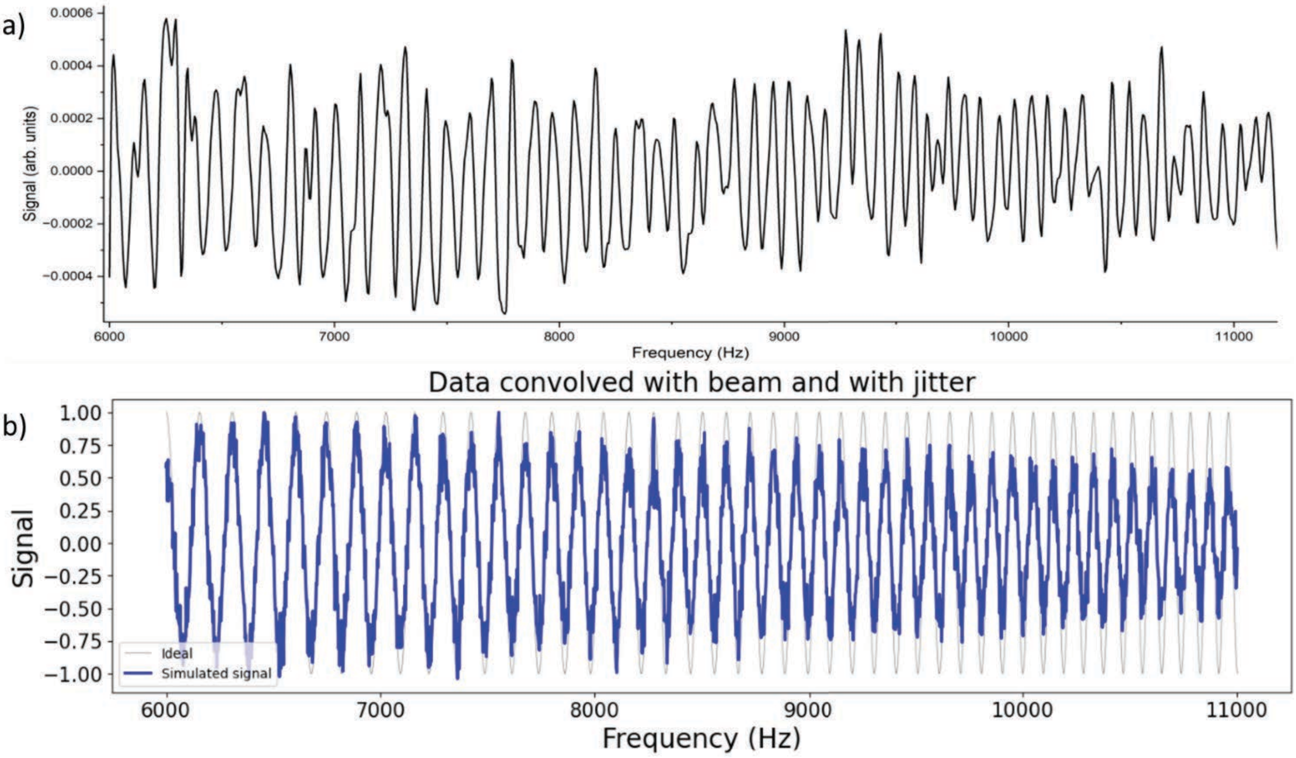

Figure 3: a) Section of a frequency sweep 1 kHz—20 kHz measured with a microfocussed beam in the off-Rowland Johann spectrometer. This demonstrates that we can reach frequencies up to 11 kHz, with the possibility to push higher with improved data processing. b) Simulated frequency sweep estimating effect of beamsize convolution, experimental noise, and position jitter.

We measured further tapes in advanced forms of degredation and were able to succesfully recover the recorded signal. This includes a magnetic recording laboratory calibration tape from 1977 with severe sticky-shed syndrome, which has led to the complete delamination of the magnetic layer across large portions of the tape (Fig. 4a,b). This tape is in even worse condition than the B. B. King recording; however by carefully scanning across regions unaffected by the delamination we were able to recover the 500 Hz test tone (Fig. 4c,d), which would be severely distorted if measured by a conventional player. Furthermore, we measured a heavily-warped acetate tape, which had completely rolled up into tubes and would be completely unreadable by conventional players (Fig. 5). The procedure for digitally unrolling the signal on these tapes with X-rays requires further development and will be the subject of a subsequent proposal. Due to the time spent developing this new methodology we were unable to measure the historic B. B. King recording as intended, but the advancements made during this experiment and the trial measurements on similarly degraded tapes have paved the way for it. A publication is currently in preparation based on these results.

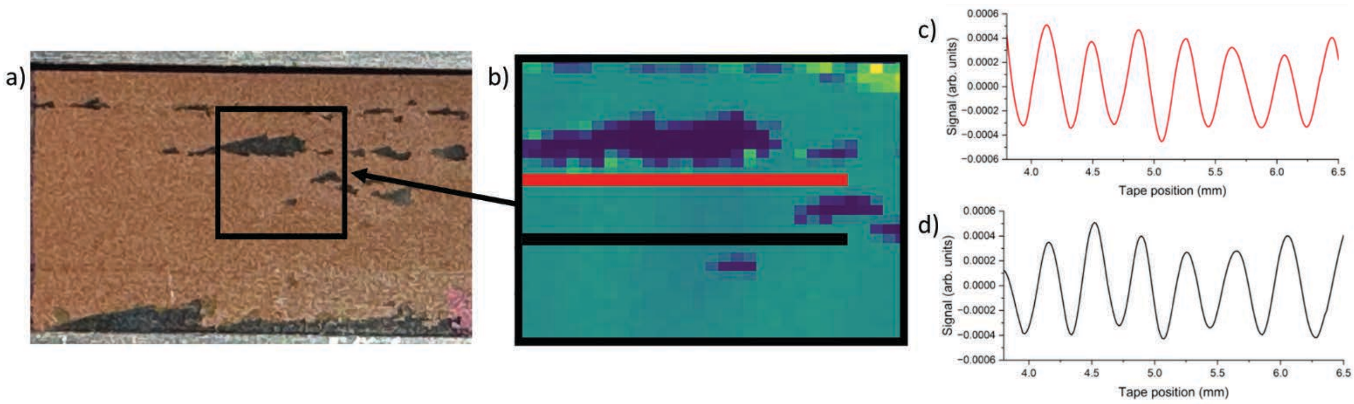

Figure 4: a) optical image of a heavily degraded magnetic tape. b) Map of integrated RIXS intensity across the boxed region in (a). The distortion is due to the 30° incident angle. (c,d) Recovered signal from linescans shown by the corresponding coloured lines in (b).

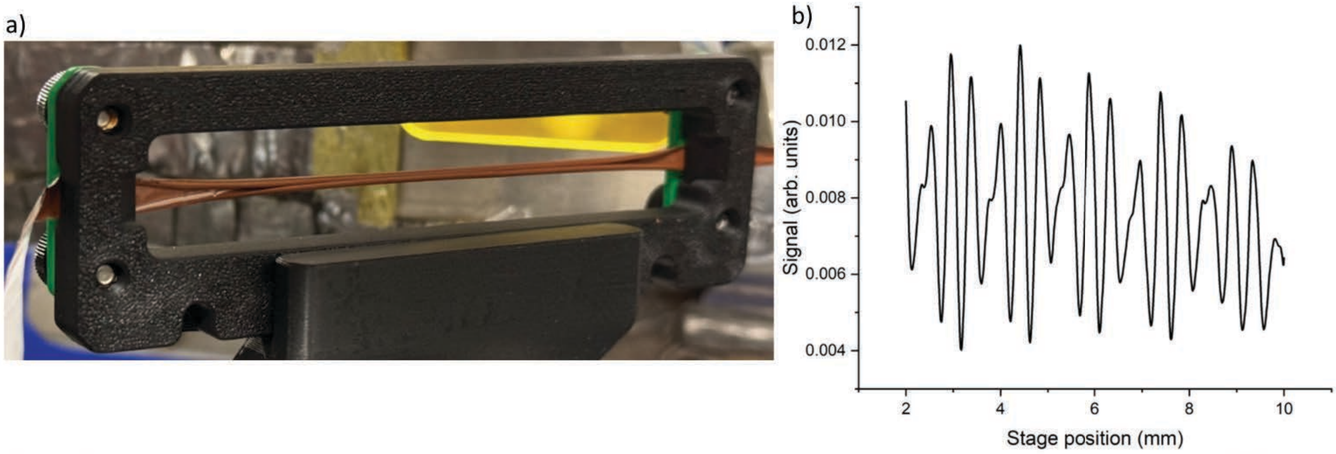

Figure 5: a) optical image of a warped acetate segment tape mounted on our tape holder. b) recovered part of a 750 + 1000 Hz recording. The clear distortions are likely due to the curved nature of the tape.