Accelerometer-Based Step Loss Detection for Open-Loop Stepper-Driven Tensile Testing Machine

Problem

The tensile testing machine uses an open-loop NEMA 36 stepper motor with a DM542T microstep driver to generate precise crosshead displacement via a 4 mm lead screw. Without a rotary encoder or linear scale, there is no closed-loop feedback to verify that commanded steps are actually executed. Step loss — where the motor skips steps under excessive load, binding, or resonance — silently corrupts displacement data, producing invalid stress-strain curves and unreliable material properties. In commercial machines this is solved with expensive encoders or servo drives. The challenge was to implement reliable step loss detection on a budget.

Approach

An ADXL345 3-axis accelerometer was rigidly mounted to the stepper motor housing to detect the mechanical shock signatures produced by step loss events. Rather than sampling vibration waveforms at the system's 10 Hz data output rate (limited by serial communication bandwidth, not the sensor), the solution leverages the ADXL345's built-in **activity detection engine**, which monitors acceleration internally at up to 3200 Hz and sets a persistent hardware flag when any axis exceeds a programmable threshold.

Key Design Decisions

- **Hardware-level detection over software analysis**: The sensor's internal comparator catches transient vibration spikes between data output intervals that would be invisible in the transmitted data stream. No DSP, no FFT, no high-speed ADC required.
- **AC-coupled mode**: The activity detector compares acceleration *changes* against the threshold, automatically filtering out static gravity. Only dynamic events (impacts, jerks) trigger detection.
- **Post-processing validation over real-time intervention**: Step loss flags each test as valid/invalid rather than attempting real-time correction. A force limit already handles overload protection independently.
- **Start-up blanking**: A 1-second delay after motor start followed by a register clear prevents false triggers from the initial acceleration ramp.

Threshold Calibration

Systematic threshold sweep using steel reference specimens (no fracture risk, unlimited repeatability). The ADXL345 THRESH_ACT register has a resolution of 62.5 mg/LSB:

Register Value	Threshold	Normal Operation	Step Loss Detected
1–2	63–125 mg	False alarms	✓
3–9	**188–563 mg**	**No false alarms**	**✓ 100%**
10+	625 mg+	No false alarms	✗ Missed

Table 1: Threshold calibration results. The usable range (3–9) spans a factor of 3×. Threshold set to 8 (500 mg) for maximum margin against false positives.

Validation Results

Test 1 — PLA, Reduced Motor Current (Provoked Step Loss)

- Step loss detected at **393 N**
- Characteristic sawtooth pattern visible in force-displacement curve after detection point
- Detection triggered on first step loss event — zero false positives during normal loading phase

Test 2 — PLA, Full Motor Current (Normal Operation)

- **No step loss detected** throughout entire test up to specimen fracture
- Clean stress-strain curve confirming measurement validity

	Step Loss Triggered	False Positives	Result
Test 1 (low current)	Yes, at 393 N	0	Correctly detected
Test 2 (full current)	No	0	Correctly passed

Table 2: Validation results summary.

Implementation

- **Firmware**: ~15 lines added to existing Arduino codebase. ADXL345 activity detection registers configured at startup. Activity flag read at 10 Hz (synchronized with data output); since the flag latches internally until read, no events are missed despite the low polling rate. Single serial event message on first detection.
- **Python control software**: Step loss flag transmitted as additional field in each data packet, stored in CSV, displayed as vertical marker line in post-processing analysis plots.
- **Hardware cost**: ~€2 (ADXL345 breakout module).

Significance

This approach demonstrates that reliable step loss detection in open-loop stepper systems does not require encoders, high-speed data acquisition, or complex signal processing. By offloading threshold comparison to the sensor's internal hardware, a €2 accelerometer provides measurement validation functionality that would otherwise require a €50+ encoder retrofit.