Vision-Based Gap Measurement System

Railway Sleeper Manufacturing - Stressing Unit

DOCUMENT PURPOSE
Plant management overview of the automated elongation measurement system for the stressing bench.

APPLICATION
High tensile steel wire tensioning and elongation monitoring (IS: 1785 Part-I, IS: 6006).

SITE CONTEXT
Railway sleeper manufacturing plant - stressing unit.

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1. Executive Summary

During railway sleeper production, **prestressing steel wire** is tensioned to a defined elongation before or during concrete casting. The wire is **high tensile steel (HTS) plain wire** conforming to **IS: 1785 Part-I** and **IS: 6006** (IRS T-39 clause 3.1.1). The stressing unit grips and pulls the wire between a **fixed bench** and a **movable anchor plate**.

This system provides **automated, non-contact elongation monitoring** with machine vision, supporting extension verification under **IRS T-39 clause 4.2** without manual scale or vernier checks in the tension zone. Bench configuration, staffing, and laser comparison details are defined in Sections 2 and 4.

Each side reports independently to a **single stressing PLC**, with a local operator dashboard for closed-loop control, traceability, and fault handling when a reading cannot be confirmed.

2. Process Context

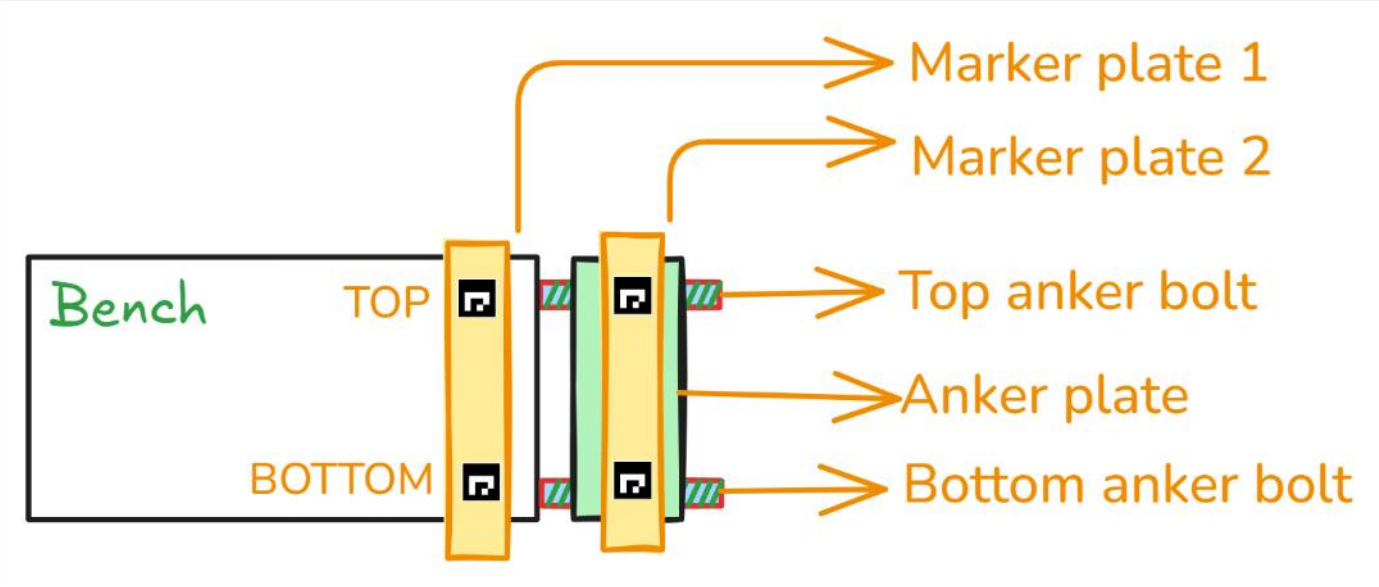
2.1 Mechanical Operation

Step	Description
1	HTS plain wire (IS: 1785 Part-I, IS: 6006) is placed and secured in the stressing bench.
2	The anchor plate grips the wire end(s).
3	Hydraulic cylinders apply force to move the anchor plate, stretching the wire.
4	Elongation is brought to the target displacement defined for that sleeper type to achieve the required prestress.
5	After hydraulics release, the anchor bolts on the anchor plate hold the wire stress; extension readings are checked to confirm the stretch was applied correctly.
6	Wire is locked and sleeper casting proceeds per plant procedure.

Accurate elongation control is essential for:

- **Structural integrity** of the finished concrete sleeper.
- **Consistent prestress forces** across all production batches.
- **Quality compliance** with design specifications.
- **Reduced scrap** caused by under- or over-stressed wire.

2.2 Measurement Location



After hydraulic pull, the anchor bolts hold prestress in the wire. The vision system measures elongation between **Marker Plate 1** (bench frame) and **Marker Plate 2** (anchor plate). Each side carries **four markers** - top and bottom on each plate - aligned with the anchor bolt positions (**eight markers** per bench). Operators confirm the stretch from outside the tension zone.

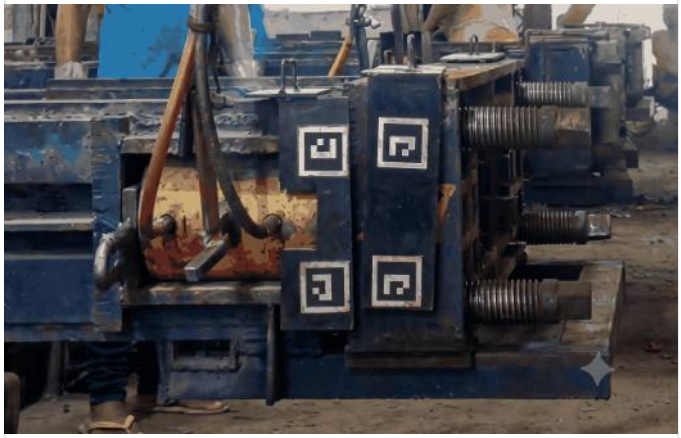
2.3 Dual-Side Bench Layout

Each bench has **two vision devices** (one per side). Sides do not share processing; each is a standalone unit reporting elongation, fault, and heartbeat to the **same stressing PLC**. The plant's current laser method uses **four sensors per bench** (two per side) for the same bolt positions. Both sides can be stressed in parallel under one PLC view.

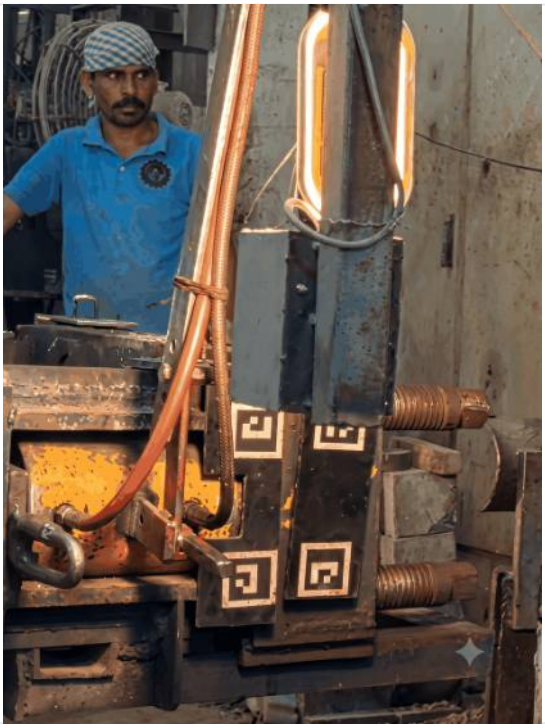
Stressing unit team: Two operators (one per side) fit marker plates and handle local bench duties; **one in-charge** monitors both sides and PLC alignment. Plates, cameras, and all measurement work stay on the **stressing unit** - not casting, curing, or other plant sections.

2.4 Live Plant Testing

Marker plates and a vision device were fitted during live plant trials. Photos below show the markers on the bench assembly and the camera view under factory lighting.



Plant floor - marker plates fitted.
Four ArUco markers on the stressing bench assembly during live testing.



Camera view - four markers in frame.
Vision device sees top and bottom markers on both plates during the pull.

2.5 Vision Camera Device

Each side uses one compact vision device (camera + processing in a sealed enclosure). Two devices cover the full bench - one left, one right - and mount on a bracket for quick place/remove at the stressing unit.

Vision camera device.
Self-contained unit with camera lens, ventilation, connector ports, and mounting bracket - one device per bench side.

3. How the System Works

The flow below applies **per side**. Hardware layout is defined in Section 2.

3.1 Extension Verification

Under IRS T-39 clause 4.2, prestressing force is verified by **measuring wire elongation**. Vision takes that reading during the stressing cycle without entry into the tension zone. Correct results depend on plate fitting, camera placement, lighting, calibration, and PLC setpoints for the sleeper type.

- **Automated elongation readings** during hydraulic pull.
- **Independent left/right monitoring** with separate dashboards and PLC links.
- **Multiple gap values per side** from the marker layout, before the wire is locked.
- **Digital records** per cycle for traceability.

When the bench arrives, each operator fits plates and places the camera on their side (**2-5 s** typical); removal takes a similar time on exit. Hardware stays on the stressing unit (see Section 2.3). The cycle proceeds when elongation is within the setpoint for that sleeper type.

3.2 Measurement Principle

The device tracks marker motion between the bench and anchor plate and reports gap in millimetres. Mounting may deviate up to **+/-10 deg** from ideal line of sight. **Vibration filtering** keeps output stable during hydraulic bench movement. Updates reach the PLC and operator screen within the plant's **1 s** cycle limit.

3.3 Reading Assurance

Uncertain readings are rejected before they reach the PLC:

- **Live camera view** - confirm markers and plate seating before pull.
- **Marker feedback** - fault if a target is missing, occluded, or not detected (no false reading).
- **Alarms** - blocked view, misaligned plates, or sensor faults.
- **Signal hold** - brief disturbance does not pass a false zero; sustained loss raises a fault.
- **Left/right cross-check** - flags uneven stretch or bench misalignment.
- **PLC interlocks** - hold or stop on out-of-tolerance elongation, unconfirmed marker, or lost heartbeat.
- **Commissioning & logs** - geometry and setpoints verified before production; readings stored per cycle.

3.4 Operator Dashboard

Each side is available from any standard screen on the plant network:

- **Live gap (mm)** for that side; combined bench view for the in-charge.
- **Live camera feed** for line-of-sight checks.
- **PLC link and system health** (connection, temperature, status).
- **Alarm text** (e.g. Marker Missing, Sensor Blocked, Plate Misaligned).

No dedicated shop-floor PC is required; each device runs independently on its side.

4. Measurement Method Comparison

Section 4.1 briefly contrasts **manual gauging** with vision. Section 4.2 compares the two **automated** options (vision vs laser) for left- and right-side elongation reported to the stressing PLC. Bench layout is defined in Section 2.

- **Current plant (laser):** four sensors (two per side); observed accuracy **+/-2-5 mm**.
- **Proposed (vision):** two devices + eight markers (Section 2); typical accuracy **+/-0.1-1 mm** under calibrated conditions.
- **Plant limit:** valid reading within **1 s**. Automated methods meet it; manual methods require stopping the cycle.

4.1 Manual Measurement Methods

Manual checks (steel scale / tape or vernier) require **pausing the pull** and placing the operator in or near the tension zone. They do not meet the plant's **1 s** response limit and have no PLC link. Vision replaces that stop-and-measure step with a continuous non-contact read.

Factor	Manual (Scale / Vernier)	Vision (This System)
Practical accuracy	+/-2-5 mm (scale) / +/-0.5-1 mm (vernier, skilled) - posture and tool angle vary between readings	+/-0.1-1 mm typical - fixed camera view every cycle
Measure during pull	No - pause and enter hazard zone	Yes - continuous while pulling
Response time (<=1 s)	Does not meet	Meets - updates within 1 s
PLC / safety	No integration; operator in tension zone	Modbus TCP; remote read on screen

4.2 Vision vs Laser (Automated Non-Contact)

Both sensor types are **movable**: placed on bench arrival, removed after stressing (**2-5 s** typical per side). Hardware stays on the stressing unit. Staffing follows Section 2.3. Accuracy and the 1 s plant limit are stated in the Section 4 introduction.

Factor	Vision - 2 Devices + 8 Markers	Laser - 4 Sensor Method (Current)
Active sensors	2 vision devices (1 per side)	4 laser sensors (2 per side)
References	8 markers (4 per side on Plate 1 / Plate 2)	4 measuring plates (one per sensor)
What is measured	Bench-anchor gap - all 4 points per side in one camera pass	Distance to each plate - one reading per sensor
PLC connections	2 x Modbus TCP (gap, fault, heartbeat)	4 x analog / IO-Link
Measuring range	Full bench stroke while markers stay in view	50 mm - 12 m (90% remission); on dark steel ~50 mm - 3.1 m per sensor
Mounting / alignment	+/-10 deg tolerance; no re-aim during pull	Must stay aimed at measuring plate throughout stroke
Vibration / environment	Filtering + signal hold; passive high-contrast markers	Affected by movement, alignment drift, scatter on wet/dirty steel
Missing target feedback	Yes - fault if marker not found	No image feedback - dropout may go unnoticed
Operator verification	Live camera feed	Red spot + LED; confirm each of 4 positions
Commissioning	Set marker geometry; commission 2 devices once	4 channels and 4x alignment per cycle

4.3 Why Vision Fits This Bench

- **Safety and cycle time** - measures during pull, meets the 1 s limit, keeps operators out of the tension zone (manual methods cannot).
- **Fewer active channels** - two Modbus devices cover the bolt positions that need four laser channels today.
- **Stable geometry** - gap from fixed marker spacing, with +/-10 deg mount tolerance and vibration filtering (Section 3).

5. Integration with Stressing Control (PLC)

Each device is a Modbus TCP peripheral on the stressing PLC, within the plant's **1 s** response window. Left and right are separate data sources; the PLC acts on each side and coordinates the bench.

Data Point (per side)	Stressing PLC Use
Gap / elongation (mm)	Live extension for IRS-style verification under fixed-load control, or optional fixed-elongation stop (Section 5.1).
System fault codes	Interlock, stop, or reject - includes missing marker, blocked view, sensor faults.
Safety heartbeat	Confirm the device is online before allowing a stressing cycle.

Typical PLC actions: stop at target; confirm both sides within tolerance before lock; cross-check for uneven tension; log values for QC.

5.1 Control Practice - Fixed Load vs Fixed Elongation

Under **IRS T-39**, prestressing is a **double-control** process: the tensioning force on the sleeper drawing is applied with a load cut-off / measuring gauge, and the **final force is also verified by measuring wire elongation**. Neither load nor elongation alone is a complete standard check.

Approach	Setpoint	What happens	Industry standing
Fixed load -> find elongation	Target load (force)	Hydraulics pull to the drawing load. Vision measures the resulting elongation for verification and logging.	Primary / IRS-aligned method - load controls the pull; elongation confirms the stretch.

Approach	Setpoint	What happens	Industry standing
Fixed elongation -> load follows	Target elongation (mm)	Hydraulics pull until vision reaches the mm setpoint. The load that develops is the outcome of that stretch.	Optional PLC mode - useful with live vision; not a substitute for IRS load control + elongation check on its own.

Both approaches use the same Modbus data (gap, fault, heartbeat). Closing the loop on millimetres during the pull needs a fast non-contact reading - which vision provides within the 1 s plant limit.

5.2 Anchor Bolt Tightness & Locking Quality

After target elongation, hydraulics release and the anchor bolts must hold tension. If the vision system detects the anchor plate sliding back after release, the PLC can flag a locking error - indicating incomplete bolt tightening on that side.

6. Industrial Reliability Features

Features for dust, oil, and vibration on the plant floor (detail in Section 3 where noted):

Feature	Benefit
Vibration filtering	Stable PLC output during hydraulic bench movement (Section 3.2).
Angle tolerance (+/-10 deg)	Camera need not be perfectly square to the gap.
Marker feedback	Fault if a target is missing or not detected (Section 3.3).
Signal hold	Brief occlusion holds last valid value instead of dropping to zero.
Automatic recovery	After power loss, unit restarts and reconnects to the PLC.
Reading comparison	PLC flags uneven tension or anchor-plate twist across sides.
Standalone operation	No dedicated shop-floor PC required.

7. Typical Deployment on the Stressing Bench

Work is on the **stressing unit only**. Team and hardware match Section 2 (two operators + in-charge; two devices + eight markers).

For each side:

1. On bench arrival - place the vision device and fit marker plates (Plate 1 bench, Plate 2 anchor); typically **2-5 s**.
2. After the cycle - remove plates and move the camera away (similar time). Hardware stays on the stressing unit.
3. Set yellow lighting and camera exposure/gain for factory ambient light.
4. Connect both devices to the plant network and register with the stressing PLC (one-time).
5. Calibrate each side and verify against known references before production.

8. Operational Benefits

Area	Outcome
Control flexibility	Supports IRS double control: fixed-load pull with elongation verification; optional fixed-elongation stop with load still monitored.
Production Speed	Faster tensioning cycles; reduces manual tape measuring and physical spot-checks.
Quality Control	Reduces human reading variation; delivers repeatable measurements tied to engineering setpoints.

Area	Outcome
Traceability	Provides a digital log of the extension achieved for each sleeper cast.
Safety	Keeps operators out of the hazard zone while high-tension forces are applied.
Maintenance	Built-in diagnostics indicate whether a fault is optical, mechanical, or network-related.

9. Error Handling and Interlocks

To protect the product, each device sends fault codes to the PLC. The PLC can then safely pause the stressing cycle on the affected side or the full bench, as configured.

Mechanical/Sensor Issue	System Response
Reference marker missing (one side)	Vision sensor detects missing target and raises a fault; PLC can halt hydraulics on that side.
Line of sight blocked (one side)	That device holds its reading briefly, then flags an error; PLC can halt hydraulics on that side.
Uneven plate travel (left vs right)	Triggers a "Misalignment Warning" when left and right elongation diverge beyond tolerance.
Sensor failure/Cable cut (one side)	That side's heartbeat drops; PLC safely interlocks until the fault is cleared.
Reading mismatch	PLC flags uneven tensioning if readings diverge beyond tolerance after hydraulic release.

10. Routine Maintenance

Each device is largely maintenance-free, requiring only basic housekeeping on **both sides** of the bench:

- Wipe down reference marker plates on the left side and right side if covered in concrete dust or oil.
- Clean both camera enclosure glass panels periodically.
- Ensure reference marker plates remain securely bolted/adhered to the bench frame and anchor plate on each side.
- Verify both devices remain connected and reporting to the PLC after any bench maintenance.