Vision-Based Gap Measurement System

Railway Sleeper Manufacturing — Stressing Unit

DOCUMENT PURPOSE	APPLICATION	SITE CONTEXT	DEVELOPER DETAILS
Plant management overview of automated elongation system.	High tensile steel wire tensioning and elongation monitoring (IS: 1785 Part-I, IS: 6006).	Railway sleeper manufacturing plant — stressing unit.	Omacsolution +91 9566699077 sridar@om90.in

1. Executive Summary

During railway sleeper production, **prestressing steel wire** must be tensioned to a precise elongation before or during concrete casting. The wire is **high tensile steel (HTS) plain wire** conforming to **IS: 1785 Part-I** and **IS: 6006**, as required under IRS T-39 clause 3.1.1. The stressing unit uses a **fixed bench** and a **movable anchor plate** to grip and pull the wire.

This system replaces manual gauging with **automated, non-contact gap (elongation) monitoring** using machine vision. Each stressing bench is fitted with **two independent vision measurement devices** — one on **each side** of the bench. Each device operates on its own, monitoring the wire zone on that side only.

On each side, **two reference marker plates** — one on the **bench frame** and one on the **anchor plate** — provide fixed reference points for consistent wire extension monitoring during stressing. The system verifies extension as required under **IRS T-39 clause 4.2**, replacing manual scale or vernier checks with automated, repeatable readings every cycle.

Both devices transmit their readings to a **single stressing PLC**, which coordinates the overall stressing cycle. Each side also provides its own operator dashboard, enabling closed-loop control, production traceability, and automated 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 must reach 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

schematic_layout.txt
```
FIXED BENCH                                 MOVING ANCHOR PLATE
(Stationary Reference)                      (Wire Holder + Anchor Bolts)
     |                                                  |
     |           <-- elongation / gap -->               |
     |                                                  |
[Plate 1] (Bench Reference)                [Plate 2] (Anchor Target)
+- Top Reference Marker                    +- Top Reference Marker (Top Anchor Bolt)
+- Bottom Reference Marker                 +- Bottom Reference Marker (Bottom Anchor Bolt)
     |                                                  |
     +----------------- HTS wire under tension -------+
```

After hydraulic pull, the anchor plate and its bolts hold prestress in the wire. The vision system monitors extension between the fixed bench reference and the moving anchor plate, allowing operators and the PLC to confirm correct stressing on each side.

Each side uses two reference marker plates: Plate 1 on the bench frame and Plate 2 on the anchor plate. Markers on these plates provide stable reference points for automated gap readings without entering the tension zone.

2.3 Dual-Side Bench Layout

Each bench uses **two devices — left side and right side** — mounted on opposite sides of the bench. They do not share processing or measurement logic; each side is a complete, standalone unit. Both connect to the **same stressing PLC**, which receives elongation, fault, and heartbeat data from each side separately.

schematic_layout.txt
```
               STRESSING BENCH (TOP VIEW)

  LEFT SIDE                              RIGHT SIDE
  +------------------------+    +------------------------+
  | [Left-side Device]     |    | [Right-side Device]    |
  |          v             |    |          v             |
  |  Fixed <- gap -> Plate|    |  Fixed <- gap -> Plate|
  |  (independent zone)    |    |  (independent zone)    |
  +----------+-------------+    +----------+-------------+
             |                             |
             +-----------+-----------------+
                         v
               SINGLE STRESSING PLC
       (left + right side data; one bench control)
```

This layout allows both sides of the bench to be stressed and monitored in parallel, while the PLC maintains a single coordinated view of the full production cycle.

Stressing unit team: The unit runs with **two operators** and **one in-charge**. Each **operator handles one side** — left or right — including reference marker plate fitting and local bench duties. The **in-charge** supervises **readings and monitoring** on both sides and confirms alignment with the stressing PLC. **All of this work stays on the stressing unit**; casting, curing, or other plant sections do not install, remove, or maintain the measurement system.

3. How the System Works

Each vision device on the bench works the same way. The descriptions below apply **per side** — the left side and right side each have their own sensor, targets, processing, dashboard, and PLC connection.

3.1 Extension Verification and Marker Layout

Under IRS T-39 clause 4.2, the final prestressing force must be verified by **measuring the extension of the wire**. This system uses automated vision to take that measurement during each stressing cycle — without manual entry into the tension zone.

Correct readings depend on proper plate fitting, camera placement, lighting, calibration, and PLC setpoints aligned with the sleeper drawing and plant quality requirements.

The system provides:

- **Automated extension readings** during hydraulic pull.
- **Independent left and right side monitoring**, each with its own sensor, dashboard, and PLC connection.
- **Multiple gap values per side** from the marker plate layout, supporting uniform stretch verification before the wire is locked.
- **Digital records** of every reading for traceability.

Reference marker plate layout: Each side uses **two reference marker plates** — Plate 1 on the bench frame and Plate 2 on the anchor plate — watched by **one vision device** that is moved into position when the bench arrives at the stressing station and moved away after stressing is complete.

Each operator fits the plates and positions the camera on **their side** when the bench is ready. Setup takes **2–5 seconds** on entry; removal takes **2–5 seconds** on exit. Plates and cameras **remain on the stressing unit** and are **not sent to the curing chamber**, which extends equipment service life.

Readings are sent to the stressing PLC and operator screen. The cycle proceeds only when extension is confirmed within the limits set for that sleeper type.

3.2 Measurement Principle

The vision device tracks marker movement between the bench reference and the anchor plate and converts it into a gap value in millimetres. Signal processing, filtering, and lighting are tuned for the stressing bay so readings stay stable under vibration and normal plant conditions. Updated values are sent to the stressing PLC and operator screen within the plant's **1 second** cycle limit.

3.3 Reading Assurance

The system rejects uncertain readings before they reach the PLC:

- **Live camera view** — operators confirm markers are visible and plates are seated before stressing starts.
- **Fault and alarm messages** for blocked view, misaligned plates, or sensor faults.
- **Signal hold and filtering** — brief disturbance does not pass a false zero; sustained loss of track raises a fault.
- **Cross-check across sides** — left and right readings are compared to detect uneven stretch or bench misalignment.
- **PLC interlocks** — the pull stops or holds if extension is outside tolerance or a device heartbeat is lost.
- **Commissioning calibration** — marker geometry and setpoints are verified before production.
- **Traceable logs** — readings are recorded per cycle for quality review.

3.4 Operator Dashboard

Each device provides a clear interface accessible from any standard screen on the plant network. For each side, the dashboard displays:

- **Live gap readings** in millimetres for that side.
- **Combined bench view** for the in-charge when monitoring both sides.
- **Live camera feed** to verify the line of sight.
- **Machine connection status** (communication with PLC).
- **System health** (sensor temperature, operational status).
- **Clear alarm messages** (e.g., "Sensor Blocked", "Plate Misaligned").

No dedicated desktop computer is required on the shop floor; each device operates entirely independently on its side of the bench.

4. Measurement Method Comparison

This system replaces traditional **manual gauging** with automated vision measurement. The tables below compare **manual methods** (steel scale / measuring tape and vernier caliper) against **automated non-contact options** (vision, laser, ultrasonic) for the same bench duty — elongation on the **left side and right side**, reporting to the **stressing PLC**.

Plant requirement: The stressing PLC cycle allows up to **1 second** for a valid elongation reading. Automated methods meet this limit; manual methods require the stressing cycle to **stop** while the operator measures.

4.1 Manual Measurement Methods

Before automation, operators typically measured bench elongation using a **steel scale** (or measuring tape) or a **vernier caliper**. Both require the operator to enter the tension zone and take a physical reading while the wire is under load — or more commonly, **pause the hydraulic pull** to measure safely.

Accuracy on manual checks is rarely limited by the scale graduations alone. Readings change when the **operator's position differs between the first and second measurement**, and when the **scale or vernier is not held square** to the gap — both are common on the stressing bench.

Factor	Steel Scale / Measuring Tape	Vernier Caliper	Vision — Reference Marker Plates (This System)
Method	Contact or near-contact — scale/tape held between bench reference mark and anchor plate	Contact — vernier jaws or depth rod span the gap; read main scale + vernier graduation	Non-contact — camera tracks reference markers on bench and anchor plates
Typical reading resolution	1 mm (steel scale); tape similar	0.02 mm (standard vernier) / 0.01 mm (digital vernier)	Sub-millimetre from calibrated marker geometry
Practical accuracy on bench	±2–5 mm — parallax, tape slack, rounded reading	±0.5–1 mm in skilled hands — but difficult to apply consistently under plant conditions	High repeatability — same automated read every cycle
1st vs 2nd reading position	Operator stands or crouches in a different position for each check — eye height and viewing point shift, so start and end reference marks appear at different graduations even for the same gap	Operator repositions hands and body between first and second measurement — jaw contact point and read-off angle change, giving inconsistent repeat readings	Same fixed camera view every cycle — no operator position variation
Angle of scale / tool placement	Scale held tilted, bowed, or not parallel to the gap axis — apparent length changes with placement angle; not square to bench/plate	Vernier held at an angle to the gap or plate face — cosine error and skewed jaw contact alter the measured span	Not applicable — gap from fixed reference marker geometry, independent of tool angle
Measure during hydraulic pull	No — operator must pause cycle and enter hazard zone	No — hands must reach into gap near high-tension wire	Yes — continuous measurement while pulling
Left + right sides	Separate manual check per side; slow; difficult to cover the full bench consistently	Separate manual check per side; slow; difficult to cover the full bench consistently	Both sides monitored automatically with logged readings
Response time (plant l i m i t "d 1	Does not meet — stop, measure, restart takes minutes	Does not meet — same delay per check	Meets — updates within 1 s
Stressing PLC integration	None — operator judgement; manual stop/start	None — operator judgement; manual stop/start	Modbus TCP — automatic stop at setpoint, fault codes, heartbeat
Digital traceability	Paper log only (if recorded)	Paper log only (if recorded)	Automatic log per sleeper cast
Operator safety	Low — operator in tension zone	Low — hands close to wire and moving plate	High — remote read on operator screen

Factor	Steel Scale / Measuring Tape	Vernier Caliper	Vision — Reference Marker Plates (This System)
Skill dependence	High — reading angle, hold steady, experience	High — access, steady grip, consistent jaw placement	Low — system reads automatically
Effect of vibration / dust	Hard to read while bench moves; dirty hands/gloves	Same — must pause pull	Filtering and signal hold maintain stable output
Cost per bench	Very low tool cost	Low–medium tool cost	Device investment; eliminates repeated manual labour

4.2 Automated Non-Contact — Bench Setup Compared

Automated non-contact elongation can use **vision with reference marker plates**, a **SICK laser distance sensor** (**DT35-B15251**) or a **Pepperl+Fuchs ultrasonic sensor** (**UB1000-18GM75-I-V15**). In all three setups, the active measurement sensors are **not permanently fixed to the bench** — they are **movable units** placed into position when the bench arrives at the stressing station, and removed/moved away once stressing is complete. Setting up the sensor and plates on entry takes **2–5 seconds**, and removing them on exit takes **2–5 seconds** for all systems.

For laser and ultrasonic systems, a measuring plate is typically fitted at the anchor top only — **one point per side**. Additional measurement points require extra sensors or repositioning, which increases cost and cycle time.

Item	Vision — Reference Marker Plates (This System)	Laser — SICK DT35-B15251	Ultrasonic — P&F UB1000-18GM75-I-V15
Reference equipment	Vision gap measurement device (repositioned per side)	Movable mid-range laser distance sensor	Movable ultrasonic distance sensor, 4–20 mA analog output, M12 connector
Sensor mounting	Movable — camera device moved to position when bench arrives, and moved away after stressing complete	Movable — sensor placed into position on entry, and removed on exit	Movable — sensor placed into position on entry, and removed on exit
Target on anchor plate	Two reference marker plates per side (Plate 1 on bench, Plate 2 on anchor) containing top and bottom markers	Measuring plate on anchor top only — not at anchor bolts	Measuring plate on anchor top only — not at anchor bolts
Measurement points	Multiple gap readings per side from marker layout	Typically one point per side; more points need extra sensors or moves	Same as laser
When bench is installed	Fit two plates per side (4 plates total) + place camera devices on entry (2–5 s total)	Fit measuring plate + place sensor on entry (2–5 s total)	Fit measuring plate + place sensor on entry (2–5 s total)
What is measured	Gap between bench reference and anchor plate markers	Distance to a single measuring plate; more points need extra hardware or moves	Same as laser
Active devices per bench	2 movable (one per side)	Typically 2 movable (1 per side); up to 4 sensors for full bolt coverage	Typically 2 movable; up to 4 sensors for full bolt coverage
Passive bench parts	4 reference marker plates total (2 per side)	Typically 1 measuring plate per side; 4 plates if covering all bolt positions	Typically 1 plate per side; 4 plates if covering all bolt positions
Cost / cycle time	2 devices — all marker readings in one pass within 1 s	More sensors and PLC channels, or repositioning — higher cost or longer cycle	More sensors and analog inputs, or repositioning — higher cost or longer cycle
Sensor & plate handling time (per side)	2–5 s to place on entry, and 2–5 s to remove/move on exit	2–5 s to place on entry, and 2–5 s to remove/move on exit	2–5 s to place on entry, and 2–5 s to remove/move on exit
Exposure to curing chamber	No — plates and cameras stay on stressing unit only; longer service life	Movable sensor and measuring plate stay on stressing unit — not sent to chamber	Same — movable sensor and measuring plate stay on stressing unit

All reference marker plate fitting, removal, reading, and monitoring described above are completed **on the stressing unit itself**. Other plant sections are **not involved** in measurement setup or plate handling.

Stressing Unit Staffing

Role	Responsibility
Operator — left side	Left-side bench work, reference marker plate install/remove, local checks
Operator — right side	Right-side bench work, reference marker plate install/remove, local checks
In-charge (1)	Reads and monitors both sides, oversees stressing PLC alignment, confirms cycle quality

Each operator owns **one side**; the in-charge provides **central oversight** without other departments sharing this duty.

4.3 Automated Non-Contact — Technical Comparison

Factor	Vision — Reference Marker Plates	SICK DT35-B15251	P&F UB1000-18GM75-I-V15
Measuring range	Full bench stroke while both markers stay in camera view	50 mm – 12 m (90% remission); on dark steel ~50 mm – 3.1 m	70 mm – 1,000 mm (90 mm – 1,000 mm adjustable); 70 mm dead band
Resolution	0.05 mm (sub-millimetre from marker geometry)	0.1 mm	0.35 mm
Repeatability	±0.1 mm (stable reading with onboard filtering)	"e 0.5 mm	±0.1% of full scale (~±1 mm on 1 m range)
Typical accuracy on bench	High — calibrated marker spacing, not dependent on steel reflectivity	±10 mm typical on natural objects (galvanised steel, oil, dust)	±1% FS linearity (~±9 mm) + ±1.5% FS temperature influence
Response time (plant limits)	Continuous updates — well within 1 s	2.5 – 96.5 ms — well within 1 s	~125 ms — well within 1 s
Effect of oil, dust, vibration	Passive markers; signal hold maintains PLC output during brief occlusion	Laser scatter and poor remission on wet/dirty steel cause dropouts	Dust, humidity, air temperature, and surface angle affect echo; wide acoustic beam
Alignment during pull	Camera is stationary in its temporary position; markers move within field of view — no re-aiming during pull	Sensor must stay aimed at top measuring plate throughout stroke	Sensor must stay aimed at top measuring plate throughout stroke
Coverage per side	Full marker layout in one pass	Typically one point; wider coverage needs more sensors or repositioning	Typically one point; wider coverage needs more sensors or repositioning
PLC interface	Modbus TCP — gap, fault codes, heartbeat per device	4–20 mA, 0–10 V, or IO-Link — one channel per sensor	4–20 mA analog — one channel per sensor; teach-in via program input
Operator verification	Live camera feed — markers visible on screen	Red laser spot + LED only; must confirm movable unit position	No image; must confirm movable unit position
Commissioning per side	Set Plate 1 & Plate 2 geometry; enter once	Typical: top only. Four bolts: mount 2 sensors per side at bolt points — 4 PLC channels, 4× alignment; or reposition 1 sensor 4× each cycle	Same — 4 sensors (cost !‘) or 4× manual reposition (time !‘)
Spares / maintenance	Replace or reprint reference marker plates; clean camera glass	Clean laser window; re-align movable sensor after handling; measuring plate wear	Clean transducer face; re-align movable sensor; measuring plate wear

4.4 Why Vision Is More Efficient on the Stressing Bench

Replaces slow, unsafe manual gauging. Steel scale and vernier methods require stopping the pull, placing the operator near high-tension wire, and relying on individual skill. Repeat readings drift when the operator's position or tool angle changes between checks. Even a precise vernier reading cannot feed the stressing PLC or stop hydraulics automatically. Vision measurement runs during the pull, meets the 1 second plant limit, and keeps the operator out of the hazard zone.

Full bench coverage in one pass. Marker plates on each side of the bench allow multiple gap values to be reported without repositioning sensors. Laser and ultrasonic layouts often cover fewer points unless additional hardware is added.

Repeatable reference geometry. Gap is derived from fixed reference marker spacing rather than how an operator holds a scale or vernier.

Better accuracy where it matters. The SICK DT35-B15251 datasheet quotes **±10 mm typical accuracy** on natural objects such as steel. The Pepperl+Fuchs **UB1000-18GM75-I-V15** offers **0.35 mm resolution** but **±1% FS linearity** (~±9 mm) and **±1.5% FS temperature drift**, with a **1 m maximum sensing range**. All automated sensor types satisfy the plant's **1 second response limit**; however, reference-marker-based vision delivers **sub-millimetre, repeatable gap readings** on **both sides** without needing precise fine-tuning of the sensor angle each cycle (the camera's wide field of view captures both markers easily).

Passive markers survive the bench environment. Galvanised anchor plates in a prestressing bay pick up oil, concrete dust, and wear. Movable laser and ultrasonic units depend on a **top measuring plate** and **manual setup/removal** every cycle — alignment drift is common. reference marker plates are **high-contrast, replaceable, and read by vision devices** on each side.

Fewer integration steps for the stressing PLC. Both vision devices send gap readings, fault codes, and heartbeat over Modbus TCP. Each laser or ultrasonic sensor needs a separate analog or IO-Link input and its own fault handling.

Lower lifecycle cost. Two temporary devices plus marker plates that stay on the stressing unit deliver logged extension readings within the plant cycle limit on every cycle.

5. Integration with Stressing Control (PLC)

Each measurement device acts as a standard sensor peripheral, communicating directly with the **stressing PLC** (via Modbus TCP) within the plant's allowed **1 second response time**. The left side and right side are separate data sources — the PLC reads and acts on each side independently while coordinating the bench as a whole.

Data Point (per side)	Stressing PLC Use
Gap / elongation (mm)	PLC monitors live extension against the setpoint for that sleeper type.
Left / Right side — System Fault Codes	Triggers interlocks, stops the cycle, or rejects the batch for the affected side or full bench as configured.
Left / Right side — Safety Heartbeat	PLC confirms each device is online and actively measuring before allowing a stressing cycle.

The PLC can:

- Compare live extension to the target defined on the **sleeper drawing** and approved stressing recipe.
- Confirm readings from both sides are within tolerance before the wire is locked.
- **Automatically stop** the hydraulic pull when target extension is reached.
- Cross-check readings across the bench to detect uneven tensioning or plate movement.
- **Log extension values** for quality control and traceability.

5.1 Suggestions & Best Practices: Anchor Bolt Tightness & Locking Quality

During the stressing operation, when the hydraulic cylinders extend the anchor plate to the target displacement, the operators on both the left and right sides tighten the anchor bolts. Once the target elongation is reached, the hydraulic pressure is released, and the anchor bolts must mechanically hold the tension without any loss of wire elongation.

Locking Verification: By utilizing the real-time feedback of the vision system, the stressing PLC can verify if the anchor plate shifts or slides back after the hydraulics release. If the camera detects that the anchor plate moves again after target release, it indicates that one or more anchor bolts were not tightened correctly. This allows the system to immediately flag a locking error, ensuring all anchor bolts are fully secured and holding the required stress.

6. Industrial Reliability Features

Designed specifically for harsh factory environments:

Feature	Mechanical / Operational Benefit
Vibration Filtering	Ensures stable readings for the PLC even when the hydraulic bench shudders.
Signal Hold	If dust or a worker briefly blocks the camera, the system holds the last valid measurement rather than dropping to zero and disrupting the PLC.
Automatic Recovery	If the plant loses power, the unit automatically restarts and reconnects to the PLC without human intervention.
Reading Comparison	Stressing PLC compares readings across the bench to flag uneven tensioning or anchor plate twist.
Standalone Operation	No fragile PC, keyboard, or mouse required on the shop floor.

7. Typical Deployment on the Stressing Bench

All steps below are carried out **on the stressing unit only** — no other plant section handles measurement hardware or reference marker plates.

Team: Two operators (left side and right side) plus **one in-charge** for reading and monitoring. Each operator is responsible for **their side** of the bench.

Repeat the following for **both the left side and right side** — two complete devices per bench:

1. When the bench arrives at the stressing station, the operator on that side moves the **vision camera device** into its temporary measurement position and fits **two reference marker plates** — Plate 1 on the **bench frame** and Plate 2 on the **anchor plate** (**2–5 s setup total**; faster with routine practice).
2. After the stressing cycle, the same operator **removes both plates and moves the camera device away** (**2–5 s removal total**). Both the plates and camera devices **remain on the stressing unit** and are **not sent to the curing chamber** or other zones.
3. Ensure high-brightness yellow light units are positioned to illuminate both sides of the bench, and configure custom camera exposure and analog gain settings to filter out ambient factory light variations.
4. Connect **both devices** to the plant's control network and register each with the **stressing PLC** (one-time commissioning).
5. Calibrate each side during commissioning and verify readings against known references before production.

8. Operational Benefits

Area	Outcome
Production Speed	Faster tensioning cycles; eliminates manual tape measuring and physical spot-checks.
Quality Control	Eliminates human error; delivers repeatable, precise measurements tied directly to engineering specs.
Traceability	Provides a digital log of the exact tension achieved for every single sleeper cast.
Safety	Keeps operators out of the hazard zone while high-tension forces are applied.
Maintenance	Built-in diagnostics clearly indicate if a failure is optical, mechanical, or network-related.

9. Error Handling and Interlocks

To protect the product, each device sends immediate 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
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.