Experimental Procedure
RIT MSD Team 12556

TEAM MEMBERS

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TITLE

Micro-Epsilon ILR1181 Plausibility Test

BACKGROUND

RIT MSD Team 12556 assignment is to develop a forging sensor system that will be able to aid in the positioning of a red hot steel billet (1700^{o}F to 2100^{o}F) within a forging dye.

OBJECTIVE

To determine if the Micro-Epsilon ILR1181 time of flight sensor can accurately measure distance from itself to a billet of metal at 1700^{o}F and 2100^{o}F to within $\pm$ 0.25 inches from 2 to 15 ft (24 to 180 in) away.

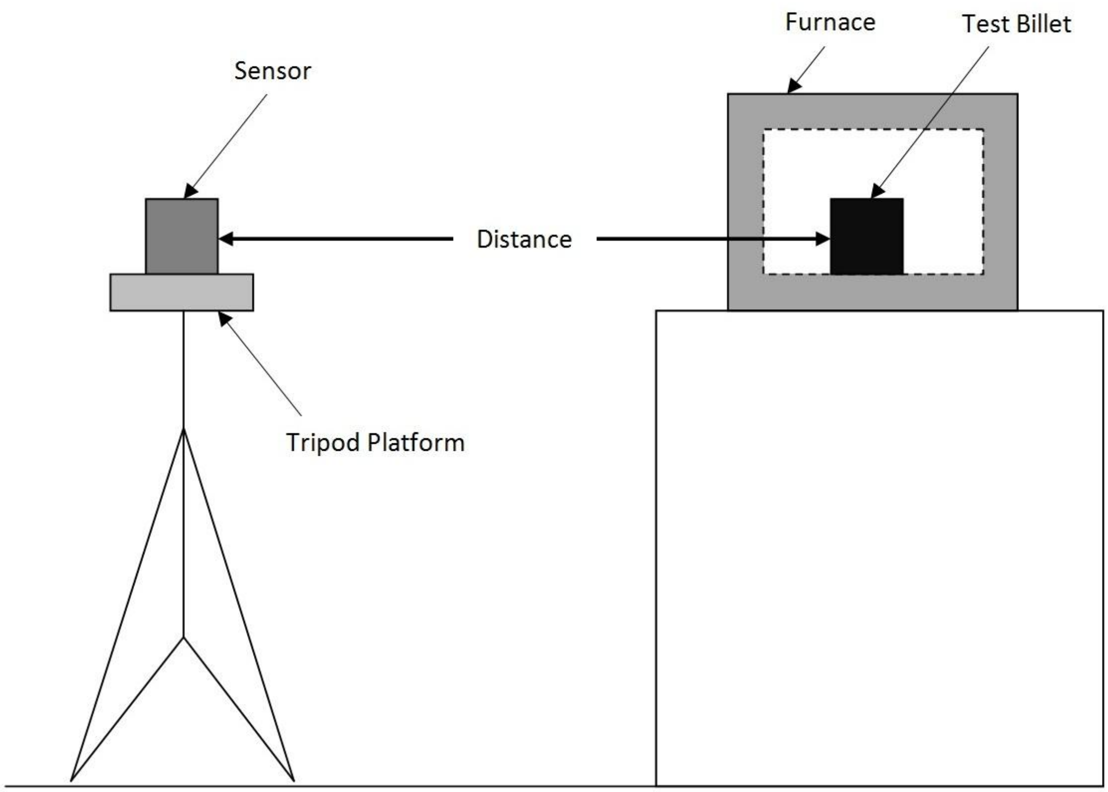
EQUIPMENT

1. (Furnace)
2. Camera tripod
3. Sensor attachment for camera tripod
4. Infrared Thermometer
5. Micro-Epsilon ILR1181 TOF sensor
6. Laptop
7. Tape measure
8. PPE

MATERIALS

1. Aluminum billet (for machined sensor-tripod attachment)
2. 4340 Steel test billet (3” x 3” x 3”)
3. Titanium test billet (3” x 3” x 3”)

SETUP



PROCEDURES

1. Zero the sensor.
    a. Turn on the sensor and hook it up to the laptop.
    b. Run the ILR1181 Tool Beta V0.6 controller software.
    c. Place the sensor on its lens cover on a table top surface.
    d. Zero the sensor within the controller software.
2. Place the test billet within the (furnace) keeping the front hatch open.
3. Setup the tripod-sensor assembly in front of the open (furnace).
    a. Attach the sensor to the tripod platform using the sensor attachment.
    b. Level the tripod's platform with the horizon using the attached bubble level.
    c. Turn the sensor on and elevate the tripod's platform, referencing the reticle of the sensor, so that the reticle hits the front face of the billet inside the (furnace).
4. Place the tripod with attached sensor two feet away from billet.
    a. Verify this distance from the front face of the billet to the front of the lens on the sensor using the tape measure and record the distance as the *Control Distance*.
    b. Verify this distance using the sensor readout and record the output as the *Cold Distance*.
5. Mark the floor where the tripod stands for future reference.

NOTE: Do not move the tripod-sensor assembly until after the *Hot Distance* is measured and recorded.

6. Using the IR Thermometer, measure and record the test billet's *Initial Temperature*.
7. Close the (furnace) hatch and heat the test billet up to 2100^{o}F.

NOTE: As the billet reaches its final temperature you may verify its surface temperature using the IR Thermometer.

After you have verified that the billet has reached its final temperature:

8. Make sure that the tripod's position has not been tampered with.
9. Turn on the sensor and laptop and run the ILR1181 Tool Beta V0.6 controller software.
    a. Verify the sensor has not been tampered with.
        i. Hold a piece of paper flush with the lens cover, the output should read zero.
10. Open the furnace and verify the billet's surface temperature.
    a. Record the billet's *Final Temperature*.
11. Measure the distance with the sensor and record the output as the *Hot Distance*.

Repeat steps one through ten for the other scenarios.

THERMAL EXPANSION

The test billet will expand in all directions when heated, therefore it is necessary to account for the linear thermal expansion in differentiating between the *Hot* and *Cold* measurements for the 4340 Steel and Titanium test billets.

$$\Delta L = \alpha \Delta T L_0$$

(http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/thexp.html)

$\Delta L =$ The change in length (linear expansion)

$\alpha =$ Coefficient of thermal expansion

$\Delta T = \frac{5}{9}\left[T_f(\,^oF) - T_i(\,^oF)\right] =$ Change in absolute temperature

$L_0 =$ Initial length = 3 in = 0.0762 m

$$\alpha_{4340}(20^oC) = 12.3\ \frac{\mu m}{m -^o C}$$

$$\alpha_{Ti}(20^oC) = 8.90\ \frac{\mu m}{m -^o C}$$

(http://matweb.com/search/DataSheet.aspx?MatGUID=fd1b43a97a8a44129b32b9de0d7d6c1a&ckck=1) -- 4340
(http://matweb.com/search/DataSheet.aspx?MatGUID=66a15d609a3f4c829cb6ad08f0dafc01) ---------------- Ti

Assuming that the test billets will expand equally in each direction, the sensor should only detect half of the overall linear thermal expansion, therefore:

$$\Delta L_{Detected} = \frac{\Delta L}{2} = \frac{\alpha \Delta T L_0}{2}$$

$$\Delta \boldsymbol{L_{Detected}} = \frac{\mathbf{5}\boldsymbol{\alpha}\left[\boldsymbol{T_f}(\,^o\boldsymbol{F}) - \boldsymbol{T_i}(\,^o\boldsymbol{F})\right](\mathbf{0.0762}\ \boldsymbol{m})}{\mathbf{18}}$$

MAXIMUM ALLOWABLE DIFFERENTIATION

The maximum differentiation between the *Hot* and *Cold* measurements will have to take into account more than just thermal expansion; it will have to account for the linearity (accuracy) of the sensor as well.

$$(Max\ Differentiation) = (Hot\ Distance - Cold\ Distance) = (d_H - d_C)$$

The published linearity for the sensor is ±5mm = ±0.2 inch. This is less than the desired accuracy of ±0.25 inch, therefore we will use ±0.25 inch in calculating the maximum allowable differentiation.

$$(d_H - d_C) < [2(Accuracy) + \Delta L_{Detected}]$$

$$Accuracy = \pm 0.25\ in = \pm 0.00635\ m$$

$$\boldsymbol{(d_H - d_C) < \left[2(0.00635\ m) + \frac{5\alpha\left[T_f(\ ^oF) - T_i(\ ^oF)\right](0.0762\ m)}{18}\right]}$$

MACHINED FACE **Test Billet Material:** 4340 Steel

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^{o}F)	(^{o}F)	(^{o}F)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

FORGED FACE **Test Billet Material:** 4340 Steel

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^{o}F)	(^{o}F)	(^{o}F)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

CONCAVE FACE **Test Billet Material:** 4340 Steel

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^{o}F)	(^{o}F)	(^{o}F)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

CONVEX FACE **Test Billet Material:** 4340 Steel

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^{o}F)	(^{o}F)	(^{o}F)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

ANALYSIS

The difference between the *Hot Distance* and the *Cold Distance* of the 4340 Steel test billet should be less that the Maximum Allowable Differentiation:

$$(d_H - d_C) < \left[2(0.25) + \frac{5(12.3e-06)\left[T_f(\,^oF) - T_i(\,^oF)\right]L_0}{18}\right]$$

If not the sensor is unusable.

MACHINED FACE **Test Billet Material:** Titanium

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^oF)	(^oF)	(^oF)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

FORGED FACE **Test Billet Material:** Titanium

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^oF)	(^oF)	(^oF)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

CONCAVE FACE **Test Billet Material:** Titanium

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^oF)	(^oF)	(^oF)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

CONVEX FACE **Test Billet Material:** Titanium

INITITAL TEMPERATURE T_i	**TEMPERATURE BOUNDARY**	**FINAL TEMPERATURE** T_f	**DISTANCE**	**CONTROL DISTANCE**	**COLD DISTANCE** d_C	**HOT DISTANCE** d_H
(^oF)	(^oF)	(^oF)	(inches)	(inches)	(inches)	(inches)
	1700		24			
	2100		180			
	1700		24			
	2100		180			

ANALYSIS

The difference between the *Hot Distance* and the *Cold Distance* of the Titanium test billet should be less that the Maximum Allowable Differentiation:

$$(d_H - d_C) < \left[2(0.25) + \frac{5(8.90e-06)\left[T_f(\,^oF) - T_i(\,^oF)\right]L_0}{18}\right]$$

If not the sensor is unusable.