A method based on ASTME1012 to adjust the alignment of the material testing machine

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Abstract. A method by using strain-gauged transducer to adjust the alignment of the materials testing machine is introduced in this paper. In order to improve the accuracy of the material test, the alignment of the material testing machine should be adjusted before tests. A transducer with three levels of strain gauges is applied before the specimens are tested. By calculating the bending stress according to the equation in ASTME1012, an adjustment suggestion to reduce the angular misalignment and concentric misalignment is given by the calculation results. Through adjusting the direction and position of the grips until the value of the strain gauges meet the requirement, the misalignment of the material testing machine will be removed.

1. Introduction
Materials testing machine is used to test the tensile strength and compressive strength of the materials. It has been shown that bending stresses that inadvertently occur due to misalignment between the applied force and the specimen axes during the application of tensile or compressive forces can affect the test results, even cause specimens to exhibit much lower strengths[1,2]. Before testing, the alignment of the machine should be adjusted. How to know the alignment of the machine and how to adjust the alignment have been the concern for the researchers. In past time, coaxiality adjustment depends on the experience or naked-eye observation of the operator. Now coaxiality can be measured in many ways. There are pull-wire method, which is easier to apply but the precision is low. Three-coordinate measuring machine (CMM) is the method with high precision mainly used by mechanical plants to measure the coaxiality of cylinder, line or cone with datum feature, but the cost is higher than pull-wire method[3]. Some researchers also reported their new methods on coaxiality measurement in different fields. There are non-diffracting beam datum-line method to measure the coaxiality for holes[4]. A novel method of establishing datum reference in shaft coaxiality measurement using multi-section and multi-probe gauges[5]. A method of determining the coaxiality eccentric errors by using three capacitive sensors is developed by Yongmeng Liu[6]. Standard practice for verification of testing frame and specimen alignment under tensile and compressive axial force application (ASTME1012) reports that there are mainly two kinds of misalignment, one is concentric misalignment which puts a “S” shaped bend in the specimen and the other is the angular misalignment which puts a “C” shaped bend in the specimen, both of them can produce non-uniform axial strains and bending strain in a specimen[7]. ASTME1012 also offers a method and equations to determine the amount of bending, which is applicable to the force in tension testing, creep testing, and uniaxial fatigue testing. Basing on ASTME1012, a calculation methods and the transducer with strain gauges are developed to get accurate results of the bending strain and a suggestion is given to guide the operator to adjust the grips to remove the misalignment before the tests.
2. Transducer preparation

A typical strain-gauged transducer has three levels of strain gauges as shown in Figure 1, Figure 2 and Figure 3, which allow the operator to determine bending strains at each level. The cross section of a strain-gauged transducer may be cylindrical, thick rectangular (those with width to thickness ratio of less than three) or thin rectangular (those with width to thickness ratio of three or larger). The transducer’s dimensions and material should match as closely as possible the actual specimens that will be tested. Twelve strain gauges are placed at the top, middle and bottom of the gauge section, each level has four strain gauges. Gauges at each level are positioned at 90° interval for cylindrical transducer, equally positioned on all four faces of the thick rectangular transducer and equally spaced on the two wide faces of the thin rectangular transducer as shown in Figure 4, Figure 5 and Figure 6. The substrate size of the strain gauges for the transducer is 4.5×8mm, sensitive coefficient K is 2.11, the resistance is 350 ohms, and supply voltage is 5-15V. The installation of strain gauges are strictly obey the method given in guidance in ASTME-E1237[8]. The strains on the transducer form 1/4 Wheatstone bridge, a compensation circuit is needed to form a full bridge. The strain gauges for the compensation circuit are same with these on the transducer installed on the testing machine. The output for each full bridge is few micro-volt, which must be amplified. A self-developed signal amplifier is used to amplify the bridge circuit signal to a few volts and change the analogy volt signal to digital signal, which is easy for computer to collect[9].

![Figure 1. Strain gauges transducer placement for cylindrical transducer.](image1)

![Figure 2. Strain gauges transducer placement for thick rectangular transducer.](image2)

![Figure 3. Strain gauges transducer placement for thin rectangular transducer.](image3)
3. Install the strain gauged transducer
Install the transducer in the upper grip first. The side with strain gauges numbered 4, 8 and 12 faces forward, which means that the operator who stand before the testing machine can see the gauges which numbered 4, 8 and 12. The installation position of the transducer is consistent with the position in calculation method. Ensure that the strain gauge's leads are not inducing any bending strain in the transducer. Clamp the transducer in the upper grip, then attach it to the lower grip. Set testing machine at as close to zero applied force as possible, then record the twelve strain gauges’ reading.

4. Calculating bending strain
After attaching the strain gauge transducer on the testing machine, the strain readings from gauge 1 to 12 are recorded. The formulas (1-6) to calculate the x axis ($B_x$) and y axis ($B_y$) bending strains of each level for cylindrical transducer are shown below:

$$B_{xx} = \frac{\varepsilon_1 - \varepsilon_3}{2}$$  \hspace{1cm} (1)

$$B_{xx} = \frac{\varepsilon_5 - \varepsilon_7}{2}$$  \hspace{1cm} (2)

$$B_{y} = \frac{\varepsilon_0 - \varepsilon_1}{2}$$  \hspace{1cm} (3)

$$B_{y} = \frac{\varepsilon_2 - \varepsilon_4}{2}$$  \hspace{1cm} (4)
\[ B_{my} = \frac{\varepsilon_1 - \varepsilon_{12}}{2} \]  

(5)

\[ B_{hy} = \frac{\varepsilon_{10} - \varepsilon_{12}}{2} \]  

(6)

\[ \varepsilon_1 \text{ through } \varepsilon_{12} \] are the strain readings from gauge 1 through 12

\[ B_{ux} \] is the bending strain of the x axis of the upper gauges, the position of x axis is shown in Figure 1

\[ B_{mx} \] is the bending strain of the x axis of the middle gauges

\[ B_{lx} \] is the bending strain of the x axis of the lower gauges

\[ B_{uy} \] is the bending strain of the y axis of the upper gauges, the position of x axis is shown in Figure 1

\[ B_{my} \] is the bending strain of the y axis of the middle gauges

\[ B_{ly} \] is the bending strain of the y axis of the lower gauges

The formulas to calculate the x axis \( B_x \) and y axis \( B_y \) bending strains of each level for thick rectangular are same with cylindrical transducer. The formulas (7-12) to calculate the local bending strains of each level for thin rectangular transducer are shown below:

\[ B_{ux} = \frac{w}{4} \left( \varepsilon_1 + \varepsilon_2 - \varepsilon_3 - \varepsilon_4 \right) \]  

(7)

\[ B_{mx} = \frac{w}{4} \left( \varepsilon_5 + \varepsilon_6 - \varepsilon_7 - \varepsilon_8 \right) \]  

(8)

\[ B_{lx} = \frac{w}{4} \left( \varepsilon_9 + \varepsilon_{10} - \varepsilon_{11} - \varepsilon_{12} \right) \]  

(9)

\[ B_{uy} = \frac{1}{4} \left( \varepsilon_1 + \varepsilon_2 - \varepsilon_3 - \varepsilon_4 \right) \]  

(10)

\[ B_{my} = \frac{1}{4} \left( \varepsilon_5 + \varepsilon_6 - \varepsilon_7 - \varepsilon_8 \right) \]  

(11)

\[ B_{ly} = \frac{1}{4} \left( \varepsilon_9 + \varepsilon_{10} - \varepsilon_{11} - \varepsilon_{12} \right) \]  

(12)

where \( w \) is the width of the thin rectangular transducer as shown in Figure 3.

\( d \) is the distance from the transducer edge to the middle of the gauge as shown in Figure 3.

A software is proposed to be developed to calculate the bending strain for each layer. The result of each layer’s bending strain will be the important criterion for the adjustment of the testing machine.

5. Methods of adjustment

Install the transducer as mentioned in part 3, record the three layers’ bending strain both x axis and y axis. In ASTM E1012-14e1, it introduces linear (concentric and parallel) and angular differences between the components on the two ends of the rigid portion of the testing machine and two shapes of transducers ("C" shape and "S" shape) that caused by misalignment. As we know that a specimen with a “C” bend has a side with higher than average strains and a side opposite with lower than average strains, a specimen with a “S” bend has a zero bending strain in the middle of its gauge section and higher than average bending strain at the top and the bottom of its gauge section. For the adjustment is related to the reading of the strain gauges and has no connection with the shape of the transducer, the following will take thin rectangular transducer as an example.
5.1. Angular adjustments

If the testing machine has angular misalignment, the transducer will appear “C” bend. Use the middle level of strain reading \( B_m \) to judge the force condition of the transducer. The calculation of \( B_{mx} \) including both bending strain of x axis \( B_{mx} \) and y axis \( B_{my} \) is mentioned above. To adjust the angular misalignment is to get the middle strain reading \( B_m \) including both bending strain of x axis and y axis of middle strain gauge as close to zero. If the bending strain of the x axis of the middle level \( B_{mx} \) is positive, the force condition of the transducer is shown in Figure 7. The adjustment of the grip is shown in Figure 8. The grip side of A90 should be loosen and the side of A270 will be tighten until the value of \( B_{mx} \) is slightly negative, then tighten A90 until the x axis reading \( B_{mx} \) is as close as zero.

Figure 7. Force condition of transducer with middle x coordinate is positive.

Figure 8. Diagrammatic sketch of adjustment.

If the strain reading of middle x axis is negative \( B_{mx} \), the force condition of the transducer is shown in Figure 9. The grip of side A270 should be loosen and the side of A90 will be tighten until the value of \( B_{mx} \) is slightly positive, then tighten A270 until the x axis reading \( B_{mx} \) is as close as zero. If the strain reading of y axis is positive \( B_{my} \), the grip of side A180 should be loosen and the grip of side A0 will be tighten until the value of \( B_{my} \) is slightly negative, then tighten A180 until the y axis reading \( B_{my} \) is as close as zero.

Figure 9. Force condition of transducer with middle X coordinate is negative.

If the middle strain reading of y axis is negative \( B_{my} \), the grip of side A0 should be loosen and the grip of side A180 will be tighten until the value of \( B_{my} \) is slightly positive, then tighten A0 until the Y coordinate reading \( B_{my} \) is as close as zero.
5.2. Concentric adjustments

Concentric adjustments are done by the upper gauge value \( B_u \) and lower gauge value \( B_l \) as guide. If the upper gauge x axis value \( B_{ux} \) is positive, the force condition of the transducer is shown in Figure 10. The grip of side A90 will be loosen, then tighten the grip of side A270 moving the upper value \( B_{ux} \) and the lower value \( B_{lx} \) together until they slightly pass each other. Then tighten the grip of side A90 to bring the upper gauge value \( B_{ax} \) and lower gauge value \( B_{lx} \) as close as possible. If the upper gauge x axis value \( B_{ax} \) is negative, the force condition of the transducer is shown in Figure 11. The grip of side A270 will be loosen and tighten A90 to move the value of \( B_{ax} \) and \( B_{lx} \) together until they slightly pass each other, then tighten the grip of side A270 making the value of \( B_{ax} \) and \( B_{lx} \) back to vertically align with each other as close as possible.

![Figure 10](image1.png)

**Figure 10.** Force condition of transducer with upper gauge x axis value \( B_{ux} \) is positive.

![Figure 11](image2.png)

**Figure 11.** Force condition of transducer with upper gauge x axis \( B_{ax} \) is negative.

The adjustment method of y axis is same with the x axis. The grip of A0 and A180 will be adjusted to make the grips aligned. If the upper gauge reading of y coordinate \( B_{uy} \) is positive, the grip of side A180 will be loosen, then tighten the grip of side A0 moving the upper value \( B_{uy} \) and the lower value \( B_{uy} \) together until they slightly pass each other. Then tighten the grip of side A180 to bring the upper gauge value \( B_{ay} \) and lower gauge value \( B_{by} \) as close as possible. If the upper gauge reading of y axis value \( B_{ay} \) is negative, the grip of side A0 will be loosen and tighten A180 to move the value of \( B_{ay} \) and \( B_{by} \) together until they slightly pass each other, then tighten the grip of side A0 making the value of \( B_{ay} \) and \( B_{by} \) back to horizontally align with each other as close as possible. It is worth to mention that when the “S” bend strains is removed, the “C” bend strain may appear. Sometimes the concentric and angular misalignment can occur together. It need to back-and-forth adjustment for several times until both of the “C” bend and “S” bend are removed.

5.3. Experiment verification

A cylindrical transducer is attached to the testing machine. Set testing machine at as close to zero applied force as possible, record the twelve strain gauges’ readings, then calculate the \( B_x \) and \( B_y \) according to the equations in (1)-(6). The results are shown in Table 1. It can be seen that the middle value of \( B_y \) (\( B_{my} \)) is nearly zero and the upper value of \( B_y \) (\( B_{uy} \)) is 95.9, while the lower value of \( B_y \)
\( B_{y} \) is -86.3, which is opposite to upper value \( B_{x} \). The results show that the transducer is "S" shape in the direction of y (shown in Figure 10). The grip of side A180 is loosen, then tighten the grip of side A0 until the upper value \( B_{x} \) and the lower value \( B_{y} \) move together, then they slightly pass each other. The final results after the adjustment is also shown in Table 1.

| Table 1. The value of strain before and after the adjustment. |
|-----------------|-----------------|-----------------|-----------------|
|                 | Before adjustment | After adjustment |
|                 | \( \varepsilon_{0} \) | \( \varepsilon_{90} \) | \( \varepsilon_{180} \) | \( \varepsilon_{270} \) | \( B_{x} \) | \( B_{y} \) | \( \varepsilon_{0} \) | \( \varepsilon_{90} \) | \( \varepsilon_{180} \) | \( \varepsilon_{270} \) | \( B_{x} \) | \( B_{y} \) |
| Upper           | 20.3            | 49.4            | -19.2           | -46.5           | 39.5       | 95.9       | 16.3          | 6.3            | -17.2           | -3.6            | 33.5       | 9.9        |
| Middle          | 15.0            | 1.1             | -19.4           | -1.9            | 34.4       | 3.0        | 13.1          | 2.2            | -15.5           | -2.3            | 28.6       | 4.5        |
| Lower           | 6.7             | -43.2           | -6.8            | 43.1            | 13.5       | -86.3      | 10.2          | 0              | -10.3           | 0              | 20.5       | 0         |

6. Conclusion
The alignment of the material testing machine not only influences the value of the test but also may cause low strength of the material. Installing the strain gauged transducer to adjust the alignment of machine every time before test. According to the formulas in ASTM E1012, the each level of bending strains of the transducer is calculated by computer software. By analyzing the bending strain both x axis and y axis, the force condition of the transducer is known. The adjustment method for "C" bend and "S" bend are discussed in the article. Finally the angular adjustment and concentric adjustment process are given in detail.

Acknowledgments
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