# EFFECT OF WIND DIRECTION SENSOR OFFSET VALUE ON UNCERTAINTY

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## ABSTRACT

This paper aims to describe the factors that affect the uncertainty in calibration of mechanical and ultrasonic wind direction sensors, to calculate measurement uncertainty to declare in calibration certificates, and to derivate the detailed formula of offset uncertainty component arising from adjusting the components used in measurement uncertainty to north of the wind direction sensor.

## INTRODUCTION

**Calibration** is a comparison between measurements – one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device. The device with the known or assigned correctness is called the standard. The second device is the unitunder test, test instrument, or any of several other names for the device being calibrated.

The calculations used in this paper is applicable to both mechanical and ultrasonic wind direction sensors. We preferred to study with mechanical wind direction sensors in our tests and case studies. Potentiometrical and optoelectronic components used inside mechanical wind direction sensors are important factors that affectthe uncertainty. Main subject of this paper is to analyze the test offset uncertainty component which is the one of most important factors. Here we will review theeffect of offset uncertainty component on total uncertainty.

Wind measurement is one of the key parameters in meteorological observation stations. So, low uncertainty levels in this measurement is very important for measuring quality. The uncertainty in the calibration certificate of the sensor used at meteorological observation station must be reduced as possible asfor this measuring quality. The uncertainty arising from mounting of wind direction sensor usedat meteorological observation station must be taken into consideration. The uncertainty component for mounting of the wind direction sensor at calibration stage and the formulation of this uncertainty component will be described later in this study.

## SECTIONS OFMECHANICAL WIND DİRECTION SENSOR

Although there are differences by brand and model, mechanical wind direction sensor is formed of two main sections :

1. Wind Vane:Mechanical part driving the sensor shaft according to wind.

2. Transducer: Center section that converts the movement received from wind vane to electrical signal. There are bearings, parts used for fixing the wind direction sensor to pole or centre physically, electronic cards  and optional heaters in this centre.

Images of some wind direction sensors:

**Figure 1-a:Images from wind direction sensors.**

**Figure 1-b: Images from wind direction sensors.**

## MOUNTING OF WIND DIRECTION SENSOR TO ANAWOS

An important point to note while mounting the wind direction sensors used in AWOS to mast or to platform is to adjustthe sensors' cursor that indicates north to the northernmost point. Otherwise even though the sensor measures the correct value, our result will be incorrect because of the incorrect offset adjustment.North adjustment of wind vane must be done carefully and in a very accurate way at the monuting stage of Automatic Weather Observation Station (AWOS).

If low measurement uncertainty is desired for wind direction sensors (this is required especially), detection of north direction and installation of sensor mıst be done with high accuracy. These are someof the most important factors affecting accuracy of Automatic Meteorological Observation Station (AWOS).

**Figure 2:Images of north cursor of different wind direction sensor models.**

Mechanical parts of the wind direction sensor has been introduced above. The north cursor is necessary to be adjusted to the northern point while mounting the two main moving sections to mast or to platform at system installation or calibration phase. Errors occuring due to this adjustment is called offset error. Offset error depends on person who made the adjustment, equipment used in direction finding methods, physical conditions, etc.

## WIND DIRECTION SENSOR CALIBRATION STAGE

**Wind Direction Sensor Test Offset Uncertainty:** This is the uncertainty originated from installation of wind direction sensor for the system at the installation or calibration stage. The most important point to be considered during the installation of sensor is adjusting the north indicator (the sign, writing or mark indicating that is necessary to set to the north) to the north. The following assembly has been established to measure uncertainties arising from this adjustment and to control the calculations. The temperature of laboratory ambient conditions were kept constant (Temperature: 23 ± 3 °C  Humidity:%45 ±10). The following components were used in the assembly.

**Figure 3-a: Theodolite      Figure 3-b:Line Laser     Figure 3- c) Interconnection Equipment**

Electronic theodolite which provided international traceability is used for reference angle measurements. Line laser is used for axis control. Interconnection equipment is used for connection between theodolite and sensors. During calibration, measurements were taken for each sensor at $45^0$ intervals in clockwise and counterclockwise directions after offset adjustment has been made. One of the most important requirements while setting the device’s orientation is that the vane’s north indicator must be within the boundaries of the laser line. This condition must be checked before taking measurement results.

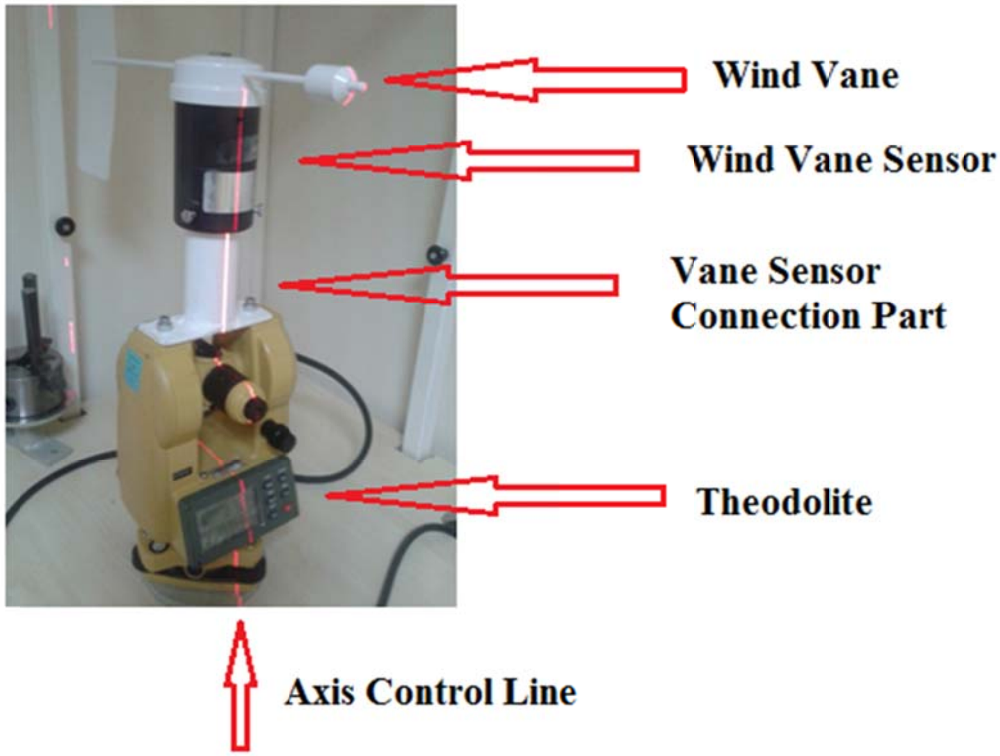


**Figure 4:Image of the devices on the axis line.**

**TEST OFFSET UNCERTAINTY**

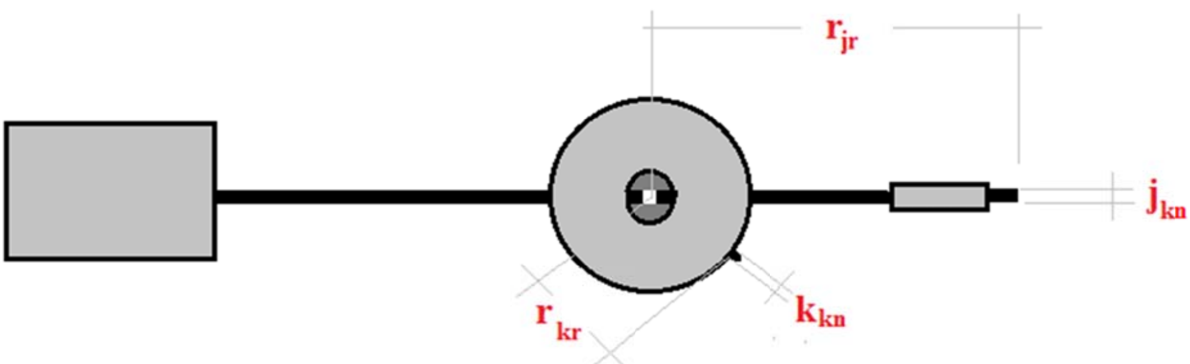


**Figure 5:Abbreviations used for Vane Dimensions.**

$r_{jr}$ = Distance from wind vane's north indicator cursor to the center of sensor
$j_{kn}$ = Width of the wind vane's north indicator cursor
$r_{kr}$ = Distance from wind vane north indicator to the center of sensor
$k_{kn}$ = Width of the vane direction indicator

The appearances and values may vary depend on brand and model, but the definitions is same for all of them.

1)In the initial phase of calibration, the laser line is fixed to the center of the reference device. To achieve that linewidth ($L_k$) of laser line on reference device is 1mm,the distance from line laser to reference device is adjusted. It is paid attention for line laser to be at the north of reference device. It is left fixed at this point.

2)- The north indicator cursor of the wind direction sensor which is connected to center of the reference device is set to indicate the line laser. This process is the process of adjusting the sensor to the northern point (considering when you look sensor-based, situation that the laser is in the north of the sensor).

3)-After fixing the sensor to north, the endpoint of vane's north cursor has to be fixed. During this process,it must be paid attention for sensor's north cursor not to drift from the northern point.

Because of the setting of the reference device was accepted to be accurate in the first stage, the uncertainty from the offset adjustment of the device will be accepted as zero(0).

In the second and third stage, width of the set points and the radii effect uncertainty. These effects will be calculated separately.

Offset uncertainty formula consists of three main components.

1-The uncertainty component caused by the linewidth of laser, width and position of vane's endpoint. The laser line must point to the vane's endpoint in all measurements.An error is occurred resulting from the difference between the largest(J2) and the smallest (J1) angles whose endpoints point to the laser. This error is a systematic error and can be calculated. The uncertainty arising from this error is called the uncertainty arising from the vane's physical structure. The error caused by this difference can be calculated by the following formula.

$$\boldsymbol{Kjh} = \frac{\mathbf{360} \,.\, |\boldsymbol{j_{kn}} - \boldsymbol{l_k}\,|}{\mathbf{2}.\boldsymbol{\pi}.\boldsymbol{r_{jr}}}$$

Because only the effect of the sensor will be examined in the system, the formula when the laser width taken zero ($\boldsymbol{L_k} = \mathbf{0}$):

$$\boldsymbol{Kjh} = \frac{\mathbf{360}\,.(\boldsymbol{j_{kn}})}{\mathbf{2}.\boldsymbol{\pi}.\boldsymbol{r_{jr}}}$$

$K_{jh}$= The error value caused by linewidth of laser, width and position of vane's endpoint.

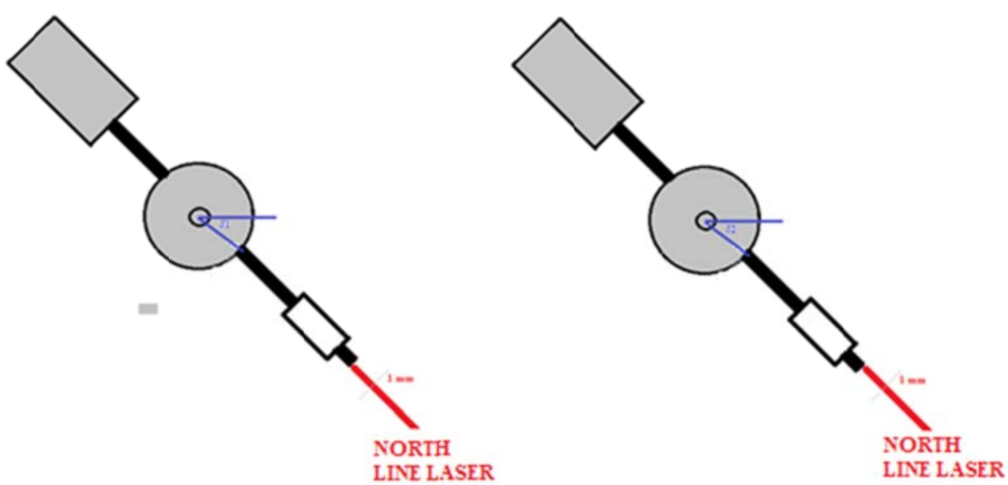


**Figure 6:Images of maximum and minimum angles showing North.**

2- The second section of the formula is the component originated from laser linewidth, width and position of the north cursor endpoint. It is the error value caused by the difference between the maximum(a2) and minimum(a1) angles of the northern point showing laser in the setup phase. The error originated from this difference can be calculated by the following formula:

$$\textit{The effect of laser linewidth, width and position of north cursor}$$

$$= \frac{360\,.\ |k_{kn} - l_k\ |}{2.\pi.r_{kr}}$$

Because only the effect of the sensor will be examined in the system, the formula when the laser width taken zero ($L_k = 0$):

$$k_{kh} = \frac{360\,.\,(\,k_{kn})}{2.\pi.r_{kr}}$$

$K_{kh}$= The error value caused by the width and position of the north cursor.

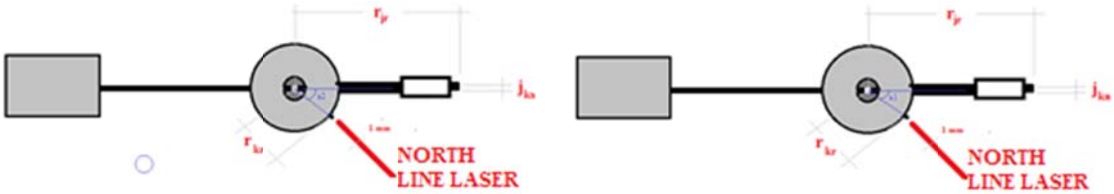


**Figure 7:Maximum and minimum values for sensor showing North.**

3- The constant valuecaused by because of the measurement errorwhich remaining constant or showing predictable changes over a set of measurements of magnitudeis a perpendicular component.

$$SYSTEMATIC\ ERROR\ CONSTANT = 2\sqrt{3}$$

Salih equation is obtained by sum of the first and second error terms.

$$SALIH\ EQUATION = 57,295.\left(\frac{j_{kn}}{r_{jr}} + \frac{k_{kn}}{r_{kr}}\right)$$

Because there is perpendicular component in the calculation of systematic error, it is multiplied by systematic error constant. As a result, the offset uncertainty can be calculated.

$$OFFSET\ UNCERTAINTY = \left(57,295.\left(\frac{j_{kn}}{r_{jr}} + \frac{k_{kn}}{r_{kr}}\right)\right)/2\sqrt{3}$$

**Calculation of Measurement Uncertainty for Calibration of Mechanical Wind Direction Meter**

$A_{correction} = f(A_{test}, A_{ref}, \delta A_{ref\,cal}, \delta A_{ref\,res}, \delta A_{ref\,drift}, \delta A_{ref\,offset}, \delta A_{test\,res}, \delta A_{test\,rep}, \delta A_{test\,offset}, \delta A_{calres}, \delta A_{calcal}, \delta A_{cal\,drift}, \delta A_{Hys\,Unc}, \delta A_{other})$

$A_{correction}$ - Difference between the angle value given from the reference and the angle value read from the test device.

$A_{test}$ - Angle value read from test device
$A_{ref}$ - Angle value given from the reference device
$\delta A_{ref\,cal}$ - Uncertainty from calibration certificate of the reference device
$\delta A_{ref\,res}$ - Resolution of the reference device
$\delta A_{ref\,drift}$ - Annual drift of reference device
$\delta A_{ref\,offset}$ - The uncertainty value when the offset of reference device done.
$\delta A_{test\,res}$ -Resolution of the test device
$\delta A_{test\,rep}$ - Repeatability of the test device
$\delta A_{test\,offset}$ - Offset uncertainty of the test device
$\delta A_{cal\,çöz}$, - Resolution of the caliper reference (meter)
$\delta A_{cal\,kal}$ -Uncertainty from calibration certificate of the caliper reference (meter)
$\delta A_{cal\,drift}$ -Annual drift of caliper reference
$\delta A_{Hys\,Unc}$ - Hysteresis uncertainty
$A_{other}$ - Other uncertainty components
$U\delta_{total}$ - Total uncertainty
$U_{meas\,unc}$ - Measurement Uncertainty

| **Source of uncertainty** | **Quantity** $X_i$ | **Standard Uncertainty** $u(x_i)$ | **Distribution factor** | **Sens. Coeff.** $c_i$ | **partial variance** $U_i$ |
|---|---|---|---|---|---|
| **Reference Calibration** | $U_{ref\,cal}$ | $U\delta A_{ref\,cal} = a_{ref\,cal} / k$ | N. | 1 | $U_{ref\,cal}^2$ |
| **Reference Resolution** | $U_{ref\,res}$ | $U\delta A_{ref\,res} = a_{ref\,res} / 2\sqrt{3}$ | Rec. | 1 | $U_{ref\,res}^2$ |
| **Reference Drift** | $U_{ref\,drift}$ | $U\delta A_{ref\,drift} = a_{ref\,drift} / \sqrt{3}$ | Rec. | 1 | $U_{ref\,drift}^2$ |
| **Reference offset uncertainty** | $U_{ref\,offset}$ | $U\delta A_{ref\,offset} = a_{ref\,offset} / 2\sqrt{3}$ | Rec. | 1 | $U_{ref\,offset}^2$ |
| **Test Resolution** | $U_{test\,res}$ | $U\delta A_{test\,res} = a_{test\,res} / 2\sqrt{3}$ | Rec. | 1 | $U_{test\,res}^2$ |
| **Test repeat.** | $U_{test\,rep}$ | $U\delta A_{test\,rep} = a_{test\,rep}$ | N. | 1 | $U_{test\,rep}^2$ |
| **Test Offset Uncertainty** | $U_{test\,offset}$ | $\mathbf{(57{,}295.(\frac{j_{kn}}{r_{jr}} + \frac{k_{kn}}{r_{kr}}))/2\sqrt{3}}$ | Rec. | 1 | $U_{testoffset}^2$ |
| **Caliper resolution** | $UA_{cal\,res}$ | $U\delta A_{calres} = a_{cal\,res} / 2\sqrt{3}$ | Rec. | 1 | $U_{calres}^2$ |
| **Caliper Calibration** | $U_{cal\,cal}$ | $U\delta_{cal\,cal} = r_{cal\,cal} / k$ | N. | 1 | $U_{cal\,cal}^2$ |
| **Caliper drift** | $U_{cal\,drift}$ | $U\delta A_{cal\,drift} = a_{cal\,drift} / \sqrt{3}$ | Rec. | 1 | $U_{cal\,drift}^2$ |
| **Hysteresis uncertainty** | $U_{Hys\,Unc.}$ | Absolute Value$(X_{i1} - X_{i2}) / \sqrt{3}$ | Rec. | 1 | |
| **Other** | $U_{other}$ | $U\delta I_{other} = a_{other} / \sqrt{3}$ | Rec. | 1 | $U_{other}^2$ |
| **Total Partial Variance** | | | | | $U_{total}^2 = \sum U_i^2$ |
| **Standard Uncertainty** | | | | | $U_{total}$ |
| **Measurement Uncertainty (k=2)** | | | | | $U_{meas\,unc} = U_{total} * k$ |

Charts below show the uncertainty results and the contribution percentage of the components making up the uncertainty for four different brand and model. Since the aim is not to compare brands and models, the brand and model names are not given. Only studies were enumerated. When calculating these uncertainty values, same measurements were made for all sensors.

Study 1

| SOURCE OF UNCERTAINTY | ESTIMATED VALUE | DISTRIBUTION | BENEFIT | STANDARD UNCERTAINTY | COEFFICIENT | PARTIAL VARIANCE | Percentage Rate |
|---|---|---|---|---|---|---|---|
| Uncertainty of Reference | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Resolution of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Annual Drift of Reference | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Offset Adjustment of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Test Resolution | 10,000000 | Rectangular | 3,46 | 2,886751 | 1 | 8,33333333 | 77,47 |
| Test Repeatibility | 0,000000 | Normal | 1,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Test Offset Uncertainty | 4,583662 | Rectangular | 3,46 | 1,323189 | 1 | 1,75083005 | 16,28 |
| Caliper Resolution | 0,100000 | Rectangular | 3,46 | 0,028868 | 1 | 0,00083333 | 0,01 |
| Caliper Certificate Uncertainty | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Caliper Annual Drift | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Hysterezis Uncertainty | 0,000000 | Rectangular | 1,73 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Other Uncertainities | 0,819964 | Normal | 1,00 | 0,819964 | 1 | 0,67234089 | 6,25 |
| | 0,000000 | | 0,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| | | | | | | | 0,00 |
| | | | | | Total Variance | 10,7575 | 100,00 |
| | | | | | Standard Uncertainty | 3,280 | |
| | | | | | Expanded Uncertainty | 6,5597 | |

In this study, the most active variable affecting uncertainty is test resolution. The reason of this is originated from the bigger resolution value of the sensor reader. Other factors affecting the uncertainty are test offset uncertainty and other uncertainties respectively.

Study 2

| SOURCE OF UNCERTAINTY | ESTIMATED VALUE | DISTRIBUTION | BENEFIT | STANDARD UNCERTAINTY | COEFFICIENT | PARTIAL VARIANCE | Percentage Rate |
|---|---|---|---|---|---|---|---|
| Uncertainty of Reference | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Resolution of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Annual Drift of Reference | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Offset Adjustment of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Test Resolution | 0,500000 | Rectangular | 3,46 | 0,144338 | 1 | 0,02083333 | 2,09 |
| Test Repeatibility | 0,000000 | Normal | 1,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Test Offset Uncertainty | 3,308020 | Rectangular | 3,46 | 0,954943 | 1 | 0,91191662 | 91,56 |
| Caliper Resolution | 0,100000 | Rectangular | 3,46 | 0,028868 | 1 | 0,00083333 | 0,08 |
| Caliper Certificate Uncertainty | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Caliper Annual Drift | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Hysterezis Uncertainty | 0,000000 | Rectangular | 1,73 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Other Uncertainities | 0,249493 | Normal | 1,00 | 0,249493 | 1 | 0,06224666 | 6,25 |
| | 0,000000 | | 0,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| | | | | | | | 0,00 |
| | | | | | Total Variance | 0,9959 | 100,00 |
| | | | | | Standard Uncertainty | 0,998 | |
| | | | | | Expanded Uncertainty | 1,9959 | |

The biggest factor affecting the uncertainty for this study is the test offset uncertainty.

Study 3

| SOURCE OF UNCERTAINTY | ESTIMATED VALUE | DISTRIBUTION | BENEFIT | STANDARD UNCERTAINTY | COEFFICIENT | PARTIAL VARIANCE | Percentage Rate |
|---|---|---|---|---|---|---|---|
| Uncertainty of Reference | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Resolution of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Annual Drift of Reference | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Offset Adjustment of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Test Resolution | 1,000000 | Rectangular | 3,46 | 0,288675 | 1 | 0,08333333 | 3,94 |
| Test Repeatibility | 0,000000 | Normal | 1,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Test Offset Uncertainty | 4,774648 | Rectangular | 3,46 | 1,378322 | 1 | 1,89977219 | 89,77 |
| Caliper Resolution | 0,100000 | Rectangular | 3,46 | 0,028868 | 1 | 0,00083333 | 0,04 |
| Caliper Certificate Uncertainty | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Caliper Annual Drift | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Hysterezis Uncertainty | 0,000000 | Rectangular | 1,73 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Other Uncertainities | 0,363690 | Normal | 1,00 | 0,363690 | 1 | 0,13227037 | 6,25 |
| | 0,000000 | | 0,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| | | | | | | | 0,00 |
| | | | | | Total Variance | 2,1163 | 100,00 |
| | | | | | Standard Uncertainty | 1,455 | |
| | | | | | Expanded Uncertainty | 2,9095 | |

The biggest factor affecting the uncertainty for this subject is the test offset uncertainty.

Study 4

| SOURCE OF UNCERTAINTY | ESTIMATED VALUE | DISTRIBUTION | BENEFIT | STANDARD UNCERTAINTY | COEFFICIENT | PARTIAL VARIANCE | Percentage Rate |
|---|---|---|---|---|---|---|---|
| Uncertainty of Reference | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Resolution of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Annual Drift of Reference | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Offset Adjustment of Reference | 0,000300 | Rectangular | 3,46 | 0,000087 | 1 | 0,00000001 | 0,00 |
| Test Resolution | 1,000000 | Rectangular | 3,46 | 0,288675 | 1 | 0,08333333 | 11,98 |
| Test Repeatibility | 0,000000 | Normal | 1,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Test Offset Uncertainty | 2,610141 | Rectangular | 3,46 | 0,753483 | 1 | 0,56773637 | 81,63 |
| Caliper Resolution | 0,100000 | Rectangular | 3,46 | 0,028868 | 1 | 0,00083333 | 0,12 |
| Caliper Certificate Uncertainty | 0,010000 | Normal | 2,00 | 0,005000 | 1 | 0,00002500 | 0,00 |
| Caliper Annual Drift | 0,010000 | Rectangular | 1,73 | 0,005774 | 1 | 0,00003333 | 0,00 |
| Hysterezis Uncertainty | 0,000000 | Rectangular | 1,73 | 0,000000 | 1 | 0,00000000 | 0,00 |
| Other Uncertainities | 0,208490 | Normal | 1,00 | 0,208490 | 1 | 0,04346798 | 6,25 |
| | 0,000000 | | 0,00 | 0,000000 | 1 | 0,00000000 | 0,00 |
| | | | | | | | 0,00 |
| | | | | | Total Variance | 0,6955 | 100,00 |
| | | | | | Standard Uncertainty | 0,834 | |
| | | | | | Expanded Uncertainty | 1,6679 | |

The biggest factor forming the uncertainty for this subject is the test offset uncertainty.

## RESULT

When the percentage values are examined, it can be seen that uncertainty is resulting from test offset uncertainty at 80%-90% ratio. In order to reduce uncertainty, it is considered to be paid attention to certain parameters in measurements and in the design of sensors. It has been seen that usage of partitioned line laser to reduce the uncertainty, can reduce effects resulting from the laser line as much as the partition ratio. In addition to this, in the sensor designs of sensor manufacturers, to make design according to these values which affects uncertainty would reduce the uncertainty much more.

In sensor design, the thickness of north indicator cursor should be too thin and the radius of its location should be as large as possible. Likewise, the width of vane's north cursor endpoint should be very small but its radius should be as large as possible.