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INFORMATION GUIDE

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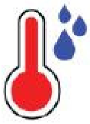
Scale errors		**Dynamic errors**	
Geometric errors		**Environment factors**	
Probe Errors		**PTB CMM Software verification**	PTB Prüfbericht Test Report

21 degrees of freedom in a CMM

A typical three-axis coordinate measuring machine tool will have 21 degrees of freedom, which translates to 21 potential sources of inaccuracy. Then there are the work-holding elements—the fixtures, clamps, chucks, vices and jaws—that add even more degrees of freedom. What are the 21 Degrees of freedom? Let’s think of them as “21 Directions of possible errors or inaccuracies” that any 3 axis vertical machine can have. The following will explain them in the easiest way we can without pictures. These errors are explained in the order they should be checked and corrected.

First, we need to cover axis nomenclature.

Let’s look at our 26 letter Alphabet. ABCDEFGHIJKLMNOPQRSTUVWXYZ

We already know that X, Y and Z are Linear Axes. We also know that A, B and C are Rotary Axes. Here we should note that the Linear Axes are used from the END of the Alphabet and the Rotary Axes are used from the BEGINNING of the Alphabet. Let’s look at how they work together. A is to X, B is to Y and C is to Z. If you put a Rotary axis on the X axis of a machine it becomes an A axis. If you put a Rotary axis on the Y axis it becomes a B axis and if you put the Rotary axis on its back rotating around the Z axis it would be called a C axis. Which direction of rotation is the positive direction? When you are looking down any linear axis in the (+) POSITVE direction CLOCKWISE is the PLUS direction for rotation. For example: you are standing on the X Minus side of a machine looking toward the X Positive side your Rotary Axis is an A axis and clockwise on the hand wheel or the + key should move your Rotary axis Clockwise. This process holds true to the other linear and rotary axes combinations.

Now on to the 21 Degrees of Freedom.

3 errors are Squareness: X of Y, X of Z and Y of Z
6 errors are Straightness: Y of X, Z of X, X of Y, Z of Y, X of Z and Y of Z
9 errors come from Roll, Pitch and Yaw. Getting 3 errors from each.

The first 3 errors are Squareness: X of Y, X of Z and Y of Z

The first of the 3 being: X of Y error. This simply means that X and Y are not square to each other. We say “X of Y” error because X is out of Square with Y. The first letter in the error states the type of error and the second letter tells us which axis is effected. Next, we have X of Z error. This means that X and Z are not square to each other. If you put a large granite square on the table in the X axis direction and put an indicator in the spindle and run it up the square you would find this error. The last of the Squareness errors are Y of Z. This is the same test we did for X of Z but rotated 90 degrees so you check the squareness of Z in the Y axis Direction.

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The next 6 errors are Straightness: Y of X, Z of X, X of Y, Z of Y, X of Z and Y of Z

These are a little more difficult to explain. It is possible to have X and Y square to each other but one or both of these axes can have straightness errors. Lets take a look down onto the X,Y plane. We see the axes are square but from the X plus side to the minus side the Axis is going down hill. Lets start separating how we describe these errors starting with the X axis. Lets put ourselves on the X plus side of the machine looking straight down the X axis. We could have errors that go in a 360 degree pattern around the straight line that the axis should follow, imagine a cone that forms from the start of the axis and opens up towards the end of the axis.

If your Axis is out Horizontally you have a Y of X error. Remember the first letter is the error and the second letter is the axis it effects. If you have Vertical error you have a Z of X error. You can certainly have both errors at the same time and to varying degrees. This is the same for the other axes. The Y axis has an X of Y error and Z of Y error. The Z axis has X of Z and Y of Z errors.

The next 9 errors come from Roll, Pitch and Yaw. Getting 3 errors from each.

Before we get into these lets talk about how an airplane flies. If you are the pilot and have the Yoke (Steering wheel or stick) in your hands and you have your feet on the rudder peddles you are ready to understand Roll, Pitch and Yaw. If you ROTATE the Yoke clockwise the plane will “ROLL” in a clockwise direction. If you pull the Yoke towards you the Nose of the Plane will “PITCH” upward. If you push hard on one of the Rudder peddles your plane will “YAW”

Roll: A of X, B of Y and C of Z

We already learned that the A (rotary) axis is associated to X. So lets look down the X axis again from the Positive side of the machine. If your axis Rolls like your airplane then you have an A of X error. The errors are described based on the axes rotary component. In this case, the rotary component moves the same way your A axis rotates, therefore you have an A of X error. The next is B of Y. the same concept holds true. Y is rotating when moved in a linear fashion and it rotates about the B axis along the way. The Z axis is the same, you would have a C of Z error. Remember C is the rotary axis that is assigned to the Z axis, so if Z is rotating on its way down it is rotating around the C axis. You have a C of Z error.

Pitch: B of X, A of Y and A of Z

Pitch follows the same rules as Roll but in relation to PITCH. So again take the X POSITIVE view and look down the X axis in the MINUS direction. Remember the airplane when you pull back on the yoke the plane pitches up, it is the same here. Imagine the X axis is high in the middle like a banana with the crown side up. This would give you a rotational component around the B axis, so the error for this condition is B of X. Lets look at the Y axis. Say Y has the crown in it. You now have a rotational component around the A axis. Remember the A axis rotates around the X axis, so this error is A of Y. Now we look at the Z axis. If Z Pitches while going down it has a rotational component that rotates about the A Axis, so you have an A of Z error.

Yaw: C of X, C of Y and B of Z

Yaw requires a little explanation. Remember the Rudder peddles on your airplane. When you pushed on one of those peddles you moved the tail of the airplane to one side. It is the same thing on your machine but the drag is not induced by air but by friction. Lets again take the same view as before. Looking down the X Minus direction and imagine the table going slowly away from you. At this point friction is induced and the table hangs up on one rail of your linear guides or your ways and causes that side of the table to hang up. This causes the table to YAW around the Z axis. You therefore have a C of X error. The same rules apply to the Y axis. If either side hangs up during travel it rotates around the Z axis and you have a C of Y error. The Z axis follows the same rules and would have a B of Z error.

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Linear error: X of X, Y of Y and Z of Z

This is the error that most people want checked and will do the least good if done before all the others. Linear error is very simply described. For a programmed distance the machine either falls short or long of that distance, so these are X of X, Y of Y and Z of Z. These errors are compensated out of your machine by using a Laser and changing your Pitch error tables in your control.

That covers the "basics" on all 21 Degrees of Freedom of a 3 Axis Vertical machining centre. The same rules apply to Horizontal machining centres as well. If you think about the rotating axes, you can determine what the errors are. If linear compensation is done before all the other errors are addressed to customer's satisfaction, you will not be getting the volumetric accuracy you require out of your equipment.

The goal is to get the machine in the condition that suits your work statement and maintain that accuracy level. The Renishaw Checking Gauge is a useful tool for diagnostics of a CNC driven machine tool. It is a DIAGNOSTICS tool only. It quickly gives you a wealth of Dynamic information about your machine, from that information you determine which tests to run next. Machine Level, Squareness and Straightness are quickly checked and corrected with a 3 axis Laser. The Roll condition is best checked with an Electronic level such as the Digital Electronic Level Metre. Pitch, Yaw and Linear are best handled again by a Linear interferometer Laser. Using the proper techniques and optics will yield you superb results.

These are the Basics in Machine Metrology. They are a great thing to know and can bring great Value to understanding why your machine isn't doing what you think it should.

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