SCALES AND WHY THEY SOMETIMES SEEM TO BE WRONG

Dear A Tech,

I recently purchased a new HEIDENHAIN DRO package from your salesman and had it professionally installed by your technician. I thought I purchased the most accurate DRO available but apparently your salesman was wrong. The very first part that I made using the new DRO was rejected by inspection. Our inspector said that the part is too large by more than 0.002” and blamed the new DRO. I ran some tests of my own and found that he is correct; the table is in fact traveling farther than the display says it is. I am very frustrated with our purchase decision. What’s going on!?

Dear Frustrated Customer,

The DRO you purchased is in fact accurate to within 0.0004” over the length of the table and your part is in fact moving 0.002” too far as described. I understand this statement may sound contradictory so let me explain. The very common error you are experiencing is called pitch error which is caused by your table traveling on an arc instead of a straight line. This arc occurs when the unsupported table sags as it is traveled from end to end. Since the part you are machining is clamped a few inches above the table, it will travel a longer path than the scale resulting in a part that is too large.

For a more technical explanation of pitch and yaw error, continue reading below…

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A TECH AUTHORITY
When Precision Counts

DEFECT OF CURVATURE OF TABLE TRAVEL ON MACHINE ACCURACY

The geometry of machines is such that a small deviation from a straight-line travel results in a large error of measurement. The errors involved are often very severe and occur regardless of the type of measuring element in use (lead screw, precision scale, laser interferometer, etc.).

Table errors are by no means limited to old machines with worn or sloppy ways. On machines with overhanging ways – such as the milling machine – large table errors will occur on brand new machines, which are in perfect condition.

Table errors are transfer errors, which result when transferring from a length reference (precision scale, lead screw, etc.) to scene of action (drill, cutter dial indicator, etc. on workpiece), some distance away.

Errors due to horizontal offset between the length reference and scene of action are called "yaw" errors; errors due to a vertical offset are "pitch" errors. For example, the lead screw of a machine is at some distance below the scene of action at the workpiece, therefore a pitch error will be involved.

Only the pitch error will be illustrated. However, the yaw error can be found similarly, and the total error of a given table is the sum of both.

An ideally perfect table movement is diagrammed on figure 1 below. Since the table moves in a perfectly straight line, the tip of the cutter (or dial indicator), the precision scale, and the lead screw all travel the same length regardless of distance "H" between them.

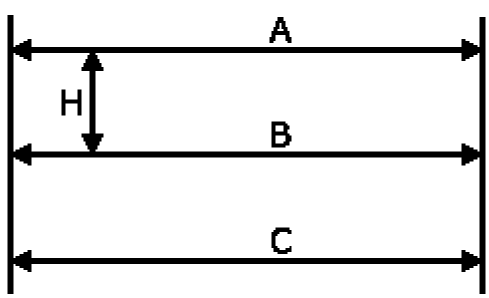


FIG.1 – Front view of a perfectly straight table travel – application point of cutter, precision scale and lead screw all travel the same length regardless of separation "H" between them.

A= The distance travelled by the tip of the cutter
B= The distance travelled by the center of the precision scale
C= The distance travelled by the lead screw
H= The difference in height in inches

In actuality, the condition shown on Fig.1 is never perfectly realized. At best it could be expected that the deviations from perfection are too small to affect the desired working accuracy on most machines. Experience has shown otherwise.

Table errors can be caused by any of the following factors:

1. Ways were not scraped straight enough or lined up well enough when the machine was built
2. Sloppy or worn ways on older machines
3. Unequal friction on ways causes table to shift slightly sideways as it travels
4. Deflection of machine members

Experience has shown that the largest table errors are most always caused by number 4, deflection of machine members. All machines, such as the common milling machine, with tables which are not supported over their full length of travel will have a very severe table error due to deflection. Figure 2 below shows the deflection of the longitudinal travel of a typical milling machine.

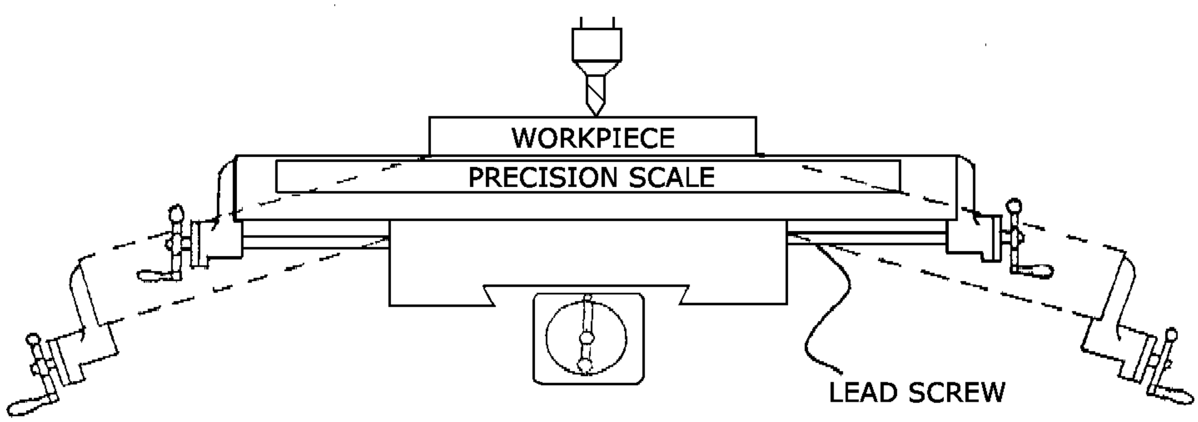
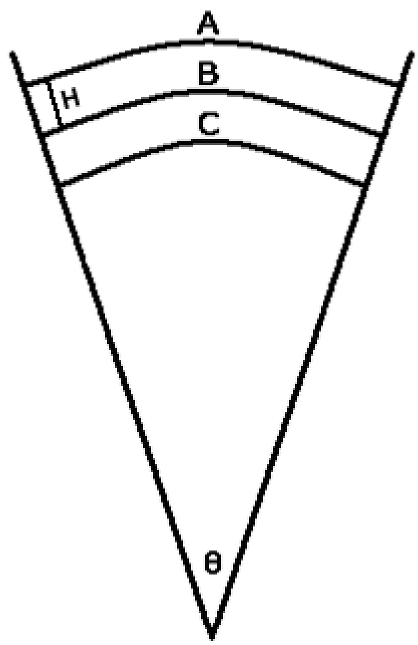


FIG.2 – Curved table travel on machine with overhanging table

Due to the unsupported weight, the tables of these machines in actuality move in a slight arc as shown by the diagram on figure 3 below.

Difference in length of travels equals error



A= The distance travelled by the tip of the cutter
B= The distance travelled by the center of the precision scale
C= The distance travelled by the lead screw
H= The difference in height in inches
θ= The change in the pitch angle of the table as it moved from left to right

FIG.3 – Front view of a slightly curved table on machines with an overhanging table – e.g. longitudinal table of a knee mill

<u>SIMPLE TEST</u>

This can also be visualized as a rim of a wheel. The error becomes greater as the vertical distance "H" from the length reference to the scene of action, and the total travel (distance from left to right) of the table increases. To prove the validity of this theory for yourself, do the following:

1. Set the length standard (i.e. gage blocks, rods, test workpiece) directly on top of the table. Take measurements.
2. Increase distance "H" by elevating length standard a few inches above the table surface. Repeat measurements.

This test proves that the table error becomes greater as the distance between the measuring device and the tip of the cutter increases.

If it where possible to put the measuring device (i.e. scale or lead screw) directly in line, and at the same height as the tip of the cutter <u>MACHINE ERROR WOULD BE ELIMINATED</u>.

The amount of table deflection "θ" can be measured very precisely by our technicians with a laser interferometer and the resultant error can be calculated by using the following formula;

ERROR=θH H= The vertical distance from the centerline of the precision scale or lead screw to the tip of the cutter or dial indicator.

θ= The change in pitch angle in radians.

For convenience, this formula is represented by the table below.

θ Change in Angle as table moves from x-y	H Distance from center of length reference to center of action						
	.5"	.75"	1"	2"	3"	5"	10"
1 sec.	.000 00	.000 00	.000 00	.000 01	.000 01	.000 02	.000 05
5 sec.	.000 01	.000 02	.000 02	.000 05	.000 07	.000 12	.000 24
10 sec.	.000 02	.000 04	.000 05	.000 10	.000 15	.000 24	.000 48
20 sec.	.000 05	.000 07	.000 10	.000 19	.000 29	.000 48	.000 97
30 sec.	.000 07	.000 11	.000 15	.000 29	.000 44	.000 73	.001 50
1 min.	.000 15	.000 22	.000 29	.000 58	.000 87	.001 50	.002 90
2 min.	.000 29	.000 44	.000 58	.001 20	.001 70	.002 90	.005 80
3 min.	.000 44	.000 65	.000 87	.001 70	.002 60	.004 40	.008 80
4 min.	.000 58	.000 87	.001 20	.002 30	.003 50	.005 80	.011 00
5 min.	.000 72	.001 10	.001 50	.002 90	.004 40	.007 30	.014 50

Example: Your table is traversed for a nominal 30", i.e. your length reference (precision scale, lead screw, laser interferometer, etc.) is set at exactly 30". The distance "H" from the scene of action (tip of cutter or indicator point) to the centerline of your length reference is 2". The change in angle "θ" as the table moved from 0" to 30" was measured to be 4 minutes. What would be the table error due to a change in pitch angle?

Referring to the table above, the error is found to be .0023". This means that at the scene of action your workpiece actually moved 30.0023".