

## The Electronic Level – Device of Many Uses

author

GEORGE J. SCHUETZ  
Director of Precision Gages  
Mahr Federal Inc.  
Providence, Rhode Island

abstract

The electronic level is a very precise instrument for indicating angular deviations. Its high resolution and fast response make it the most practical device for measuring the flatness and straightness of horizontal surfaces such as machine ways, surface plates and alignment of instrument platforms. The level is explored in terms of its basic operation, use in machine tool and other unique applications. Examples of these applications, along with typical presentations of their results are supplied.

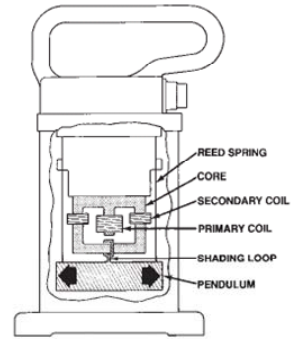
conference

International Manufacturing  
Technology Conference 90  
September 6, 1990  
Machine Design  
Chicago, Illinois

index terms

Measurement  
Utilization

The level system consists of a pendulum-type sensing head and an electronic amplifier with readout calibrated in seconds of arc. This figure details the principal of operation of the sensing head. The pendulum is supported by two reed springs attached to an extension block at the top of the sensing head's housing. Tilting the sensing head causes a change in the position of the pendulum shading loop in relation to the center leg of the core. This produces an electrical unbalance in the amount of flux passing through the two secondary coils, delivering a signal proportional to the displacement of the pendulum. This is displayed on the amplifier in seconds of arc.



The advantages of the level compared to other sensing devices are important to consider:

**Speed of Response**

The level is very fast to respond to slight angular changes. This allows for fast movement of the sensing head to various measurement positions or the head can be left at the measurement position while dynamic readings are being taken of its position.

**Resolution / Repeatability**

When compared to spirit levels, the electronic level can resolve to .1 arc seconds (6u"/ft.) while spirit levels resolve only to .0001/ft. Repeatability of the level is +/- .1 arc second.

**Ease of Use**

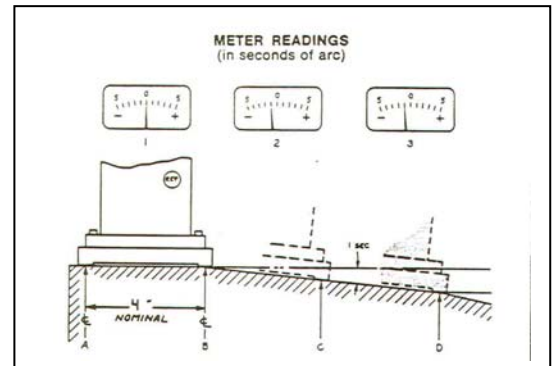
Often, the level is compared to the auto-collimator or a laser calibration system. In each measurement case, the technique is basically the same. However, the level is much easier to setup and operate. Results are obtained in a cost effective manner without time-consuming alignment of slight path alignment, no optical surfaces to keep clean and it does not need a turbulence-free environment to achieve accurate readings.

**MEASUREMENT**

In most instances, the contour or straightness of a surface is most meaningful when presented in terms of linear displacement from a reference line.

In a typical profile application, measurements are made by moving the sensing heads in convenient increments in a path along the surface to be checked. Comparative readings are taken at each successive position of the head.

This figure shows the first move from a reference position (1) indicating a downward slope of one second of arc. This represents a 5 micro-inch / inch drop over a span of 4", placing Point "C" at an elevation of 20 micro-inch / inches below Point "B". The second move indicates the same degree of slope, placing Point "D" at an elevation of 40 micro-inches below Point "B". This is from totaling the deviations at Point "C" and "D".



The fact that the electronic level can communicate with computers, allows for economical, fast and error-free calculations to be made automatically.

**APPLICATIONS**

Applications for this device can be classified as the following:

1. To show any deviation in the right-angle relationship between a horizontal surface and the earth’s gravitational force (usually expressed as an angular or linear deviation from absolute level)...or to show any change in this relationship over time.
2. To compare the orientation (attitude) of separate or adjacent horizontal surfaces...or to show any change in this comparison over a period of time.

**Surface Deviation**

In the first application, there are a number of variations.

In its purest form, the level is adjusted using the zero control so that reversal of the sensing head (180 degrees) produces an identical meter reading on both sides of center “zero”. Once adjusted in this manner, the instrument functions purely as a spirit level.

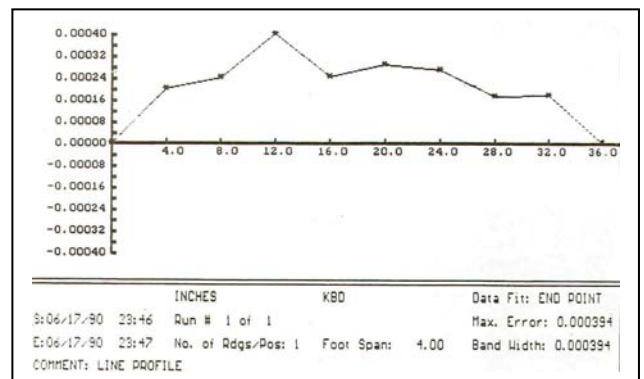
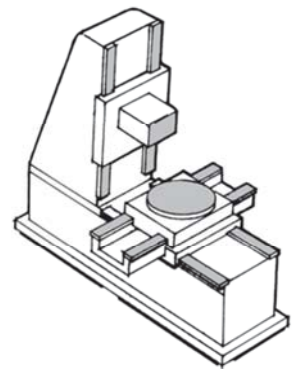
The accuracy of machine tools begins with proper levelness plus the relationship between the ways and the table. During the manufacturing process, installation and surveillance, these relationships are critical.

Shown here are just a few of the many surfaces that can be checked on a machine tool using the electronic level.

By placing the electronic level on the surfaces, the system will check, to a very high degree of accuracy, the overall levelness of the machine components.

**Straightness**

The next step is to move from the overall levelness of the machine to the straightness of the various ways. This is accomplished by starting at one end of the surface to be measured and moving the sensing head in convenient increments along the path to be profiled. Readings are taken at each successive position of the level and fed into a data collection system. A straight edge is used to assure a straight line path of movement. The usual increment of movement is equal to the distance between centerlines of the rest pads at either end of the sensing heads base.



The computer allows for easy collection and display of this data. A typical printout of the surface profile is shown below.

**Differential Sensing**

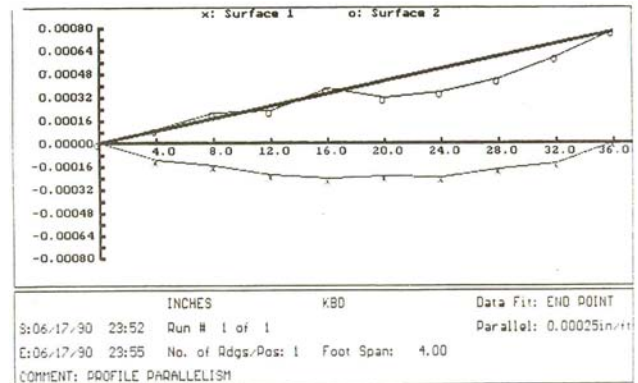
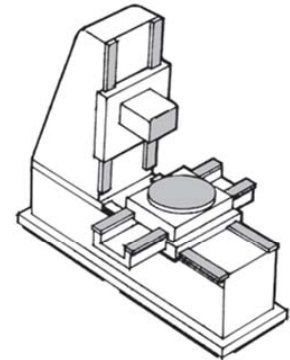
A great aide in this and similar profiling applications is the use of two level sensing heads operating simultaneously with a single amplifier. When the sensing heads are arranged for opposite response to a common motion (such as vibration or a shift in attitude of the object whose surfaces are being compared), they will ignore it responding only to changes which affect the two sensing heads differently. Therefore, a deviation in flatness, squareness, parallelism or alignment can be accurately determined even though the object (such as a surface plat or machine) does not maintain constant orientation.

**Profile Parallelism**

Now, using two heads, relationships may be measured between the surfaces. For example, the parallelism between two ways may be checked. While this does not show the relative height between the heads, it does show the attitude between the surfaces.

Here, straightness checks are made of each way without moving the reference head.

The computer program can then print out the relationship between both ways showing straightness and parallelism.

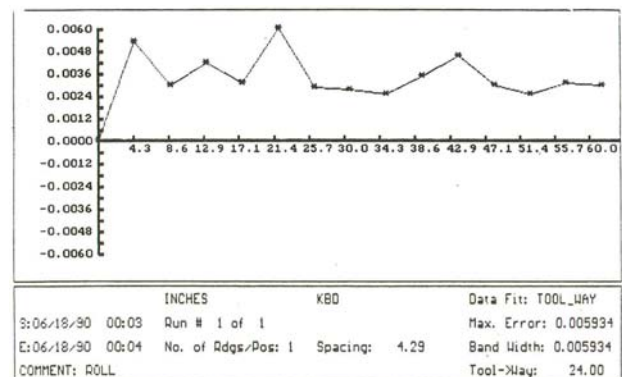
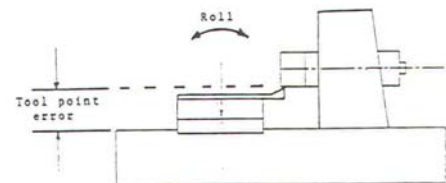


**Pitch and Roll**

Another variation of straightness on a lathe is pitch and roll of the headstock as it moves along its path.

Here, the reference level is placed on the machine while the sensing head is placed on the head stock. The head stock is then moved in increments along its path.

Knowing the height of the tool above the ways, the computer will calculate the error produced at the tool point.



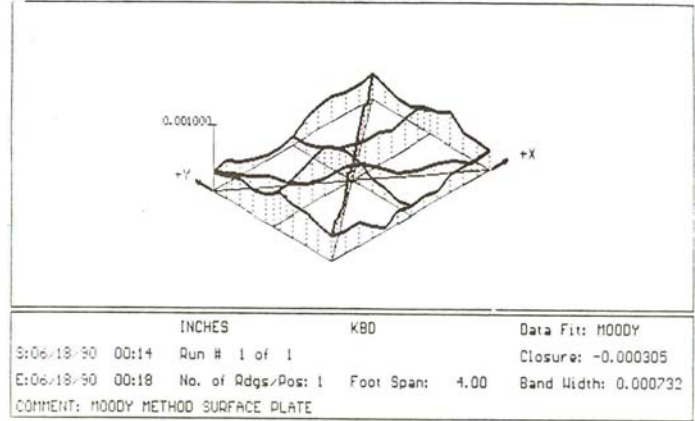
The chart displays the tool point error.

**Surface Flatness**

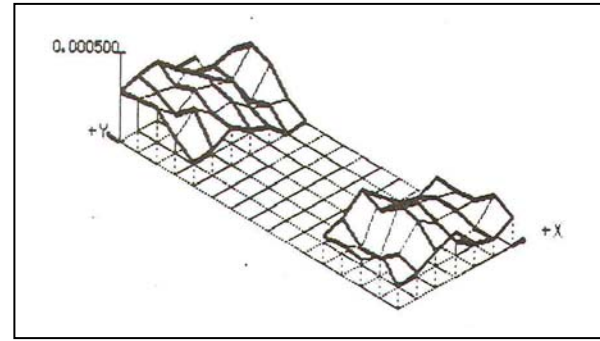
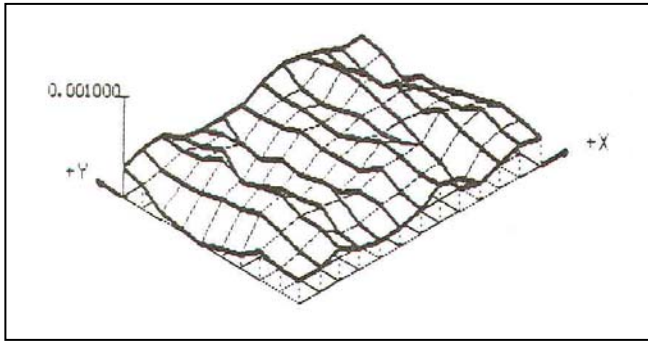
The next progression in the collection of data is to combine a number of straightness checks made on a surface into a single chart. This is useful for checking surface flatness on machine beds and surface plates.

The Moody Method for checking surface plates has been used for years to check flatness. The electronic level is a fast and accurate way to check these plates.

Using the straight edge as a guide, the level moved at the locations indicated to produce the surface profile.



On larger plates or machine table tops, the Moody Method leaves areas critical in use unmeasured. In these cases, a grid pattern is used to collect data. By following an X-Y pattern, data can be generated to produce a very accurate picture of the table top.

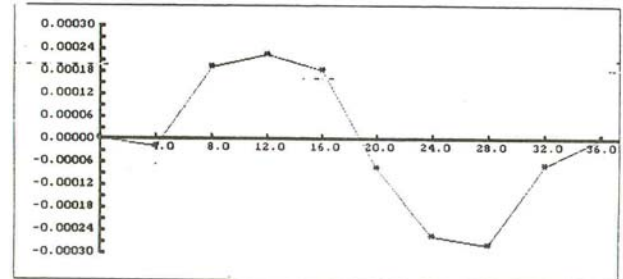
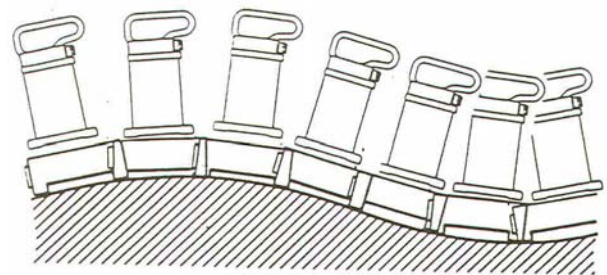


Like PROFILE PARALLELISM, two grid patterns may be combined in a single chart. While this does not show the height relationship between the two surfaces, it does give an indication of the relationship of attitude between the surface.

**ACTIVE LEVELING SYSTEMS**

In some cases, especially on large surfaces, the movement of a single head doing a large number of paths is tedious and time-consuming. By using a number of level heads mounted on carriers and placed on machine ways, a computer can monitor the levels and construct a dimensional profile of the way and display it for the operator. This is done in real time so that the profile of the way is active.

Now, the operator can watch as leveling adjustments are made and the machine is brought into level and the way made straight.



By combining a series of these measurements, a footprint of a machine can be made for analysis and future reference.

## **SURFACE ATTITUDE**

In this class of application, the level does not have to be adjusted for a specific relationship to absolute level and does not function as a true level but rather as an attitude comparator.

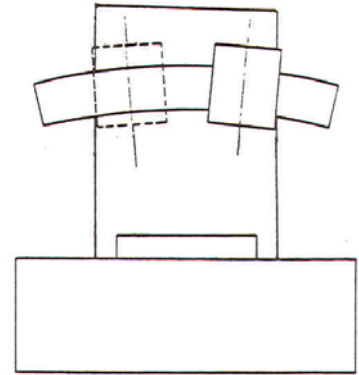
If the surface areas being compared are contiguous portions of a larger surface, the level functions as a linear geometry indicator. If the surfaces are at remote surfaces, the level functions as a level alignment tool. In both cases, the level competes with optical alignment tools but without critical sight path alignment.

### **In-Process Machine Alignment**

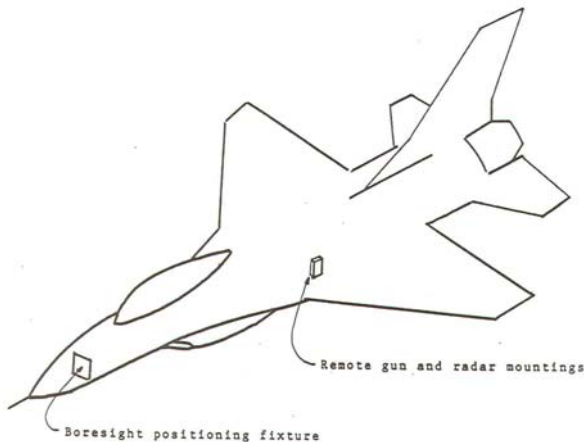
Since the differential level provides high speed of response and is immune to like vibrations on the heads, it is a useful tool in in-process machine alignment.

On many machines, the movement of the head or machine bed to its extremes puts tremendous loading on the machine. This can cause misalignment of critical ways and produce tool point error. The level can be used to sense this alignment error and then the machine can be designed to correct for this alignment error.

A machine head puts tremendous strain on the machine way causing tool point error. This machine can be instructed to read the difference between the levels after the head is moved to position. If the way is not within an allowable error, automatic mechanical alignment is made at the slide. This correction puts the tool point at its correct location and the machining process is continued.



## **BORE-SIGHT ALIGNMENT**



Alignment of weapons and sensors on military aircraft is critical to the aircraft ability to deliver its armaments and self-defense. The electronic level offers a fast, accurate method of aligning pitch and roll without critical sight path alignment.

In the above, the reference head is mounted to the reference bore-sighting fixture. The sensitive head is then moved to various radar and weapon mounts. By mounting the heads in the pitch and roll direction, the mounts may be brought into the same attitude as the reference head.

## **RADAR PLATFORM ALIGNMENTS**

The distance between sensing heads is not limited to the area of a machine tool or aircraft. Through signal conditioning, the head can be made to operate at distances of 2000 ft. and longer. This is important when alignment of radar or gun platforms is required.

Once again, the remote sensing head is moved to the various station and compared to the reference plate. This type of operation is fast, accurate and does not require sight path holes for alignment.

## **SHIP-BOARD STRESS**

Stress on submarines is tremendous and different when being built as opposed to their sea conditions.

In dry-dock, they tend to take a bowed down condition because of lost of ballast and weight distribution. Under running conditions, they tend to take a bowed up condition. It is critical to monitor this amount of stress. The level proves to be a fast accurate way to accomplish this. Its fast response and high resolution make this an ideal application.

## **CONCLUSION**

Electronic levels have broad applications in the machine tool industry. Their fast response, high accuracy and resolution are ideal for today's critical alignment requirements.

In combination with a computer and software, the electronic level system permits quick, high accuracy measurement of virtually any horizontal surface for levelness, straightness, flatness, parallelism and squareness. Using differential heads, the level system provides high resolution profiling even under conditions where ambient noise and vibration are prevalent.