



## Increased Accuracy in -hp- Meters Through Servo Calibrating Methods

For some time, -hp- has been processing the precision-class meters used in -hp- equipment in a way believed unique in the industry. The method consists of using a specially-developed machine that automatically prepares an individual meter scale for each individual meter in the same sense that a hand-calibrated scale is

individually prepared for a meter. Besides giving extremely high calibration accuracy of about  $\frac{1}{4}$  of 1%, the calibrator also gives each meter a performance inspection of unparalleled rigor.

In the article that follows, Bernard M. Oliver, -hp- vice-president for R & D, describes the new meter calibrator and the results it has given.

**D**ESPITE the development of newer indicating methods such as digital display systems and accurate oscilloscopes and recorders, the long-used d'Arsonval meter continues to be a very important indicating device in electronic measuring equipment. It is cheaper than any other readout device of comparable accuracy, except perhaps in the case when the data is already in digital form. Being an analog device, it is more

convenient than a digital readout for such operations as tuning for a maximum or a null. It is relatively simple and can be made rugged, long-lived and trouble-free. Because of these advantages it will undoubtedly continue to be widely used in applications where accuracies of one percent or slightly better are sufficient.

Since many -hp- instruments use and will continue to use d'Arsonval meters for indi-

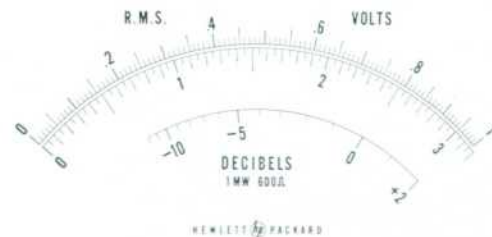


Fig. 2. (above). Typical high accuracy meter scale prepared by calibrator. Scale reproduced at half full size.

Fig. 1. (at left). The Hewlett-Packard Automatic Meter Calibrator prepares high accuracy meter scales tailored to individual meter. Meter being calibrated is held face-in at center of calibrator panel. Calibrator also provides a signal that can be used to analyze performance of meter being calibrated.

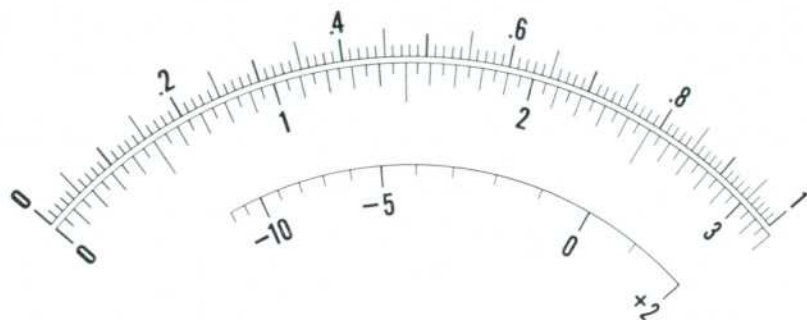


Fig. 3. *Reproduction of meter scale processed 5 times by calibrator. Both meter and scale were removed and re-inserted between successive runs. Excellent repeatability of both meter and calibrator are evident here. Scale reproduced at 90% of full size.*

cations (vacuum tube voltmeters being a specific example), a program was begun several years ago at *-hp-* to improve the accuracy of the meters used in *-hp-* instruments. It was our original intent to develop a machine that would automatically produce individually-calibrated scales for our precision meters. This plan was based on the fact that, in general, even supposedly linear meters actually exhibit considerable departure from a linear deflection-vs.-current characteristic. This occurs because the flux in the airgap is not absolutely uniform due to such factors as variations in the radii of pole faces, centering of pole faces, partial saturation of pole tips, centering of the core, etc. The resulting departure from a linear deflection characteristic is called "tracking deviation."

Because of the tracking deviation effect, in many cases the only difference between a meter of higher accuracy and one of lesser accuracy is the scale match. For simple indicating meters of low accuracy a single pre-printed scale is usually used. For meters of higher accuracy, however, several pre-printed scales may be prepared to take into account the non-linearities in the deflection vs. current characteristic of the meters. Thus, for meters having in the order of 2% accuracy, past practice has been to prepare three standard pre-printed scales differing slightly in shape or linearity. The tracking de-

viation of each movement is then measured at appropriate points and the standard scale selected which best matches the actual deviation. When meters are to be calibrated to an accuracy of 1%, six standard scales are generally required and the selection job is much more difficult. For still higher accuracies, the pre-printed scale approach becomes impractical and expensive individually hand-calibrated scales are used.

Obviously, the choice of a pre-printed scale to reduce tracking error is a compromise procedure. Rarely will one of the available scales be exactly right for a particular meter. As a result, most meters so produced may be limited in accuracy by lack of precise scale match rather than by their inherent lack of adequate repeatability of reading. In fact, in many commercial meters the only difference between an expensive meter of 1% accuracy or better

and a cheaper, less accurate model is the pains taken in obtaining proper scale fit. The motors themselves may be identical. It was concern over this loss of potential accuracy that led to the development at Hewlett-Packard of a totally new automatic calibration procedure.

#### THE *-hp-* METER CALIBRATOR

The original concept of developing a machine to produce individually-calibrated scales for our precision meters was accomplished and the resulting meter calibrator is in regular production use today. Over and beyond this primary objective, however, the meter calibrator provides a very sensitive means of evaluating meter performance. It reveals defects scarcely detectable by more conventional tests and does so without breaking the manufacturer's seal. As a result, all *-hp-* instruments processed by the calibrator receive a very sophisticated 100% incoming inspection and any meters showing unsatisfactory operation in any respect are rejected.

A photograph of the calibrator is shown in Fig. 1. The completely assembled meter, in its case but without scale, is placed in a centering fixture. The meter is then supplied a current which, in the absence of tracking deviation, increases linearly from zero to the full scale value. The meter responds to this current and the position of the pointer is tracked optically. Any tracking de-

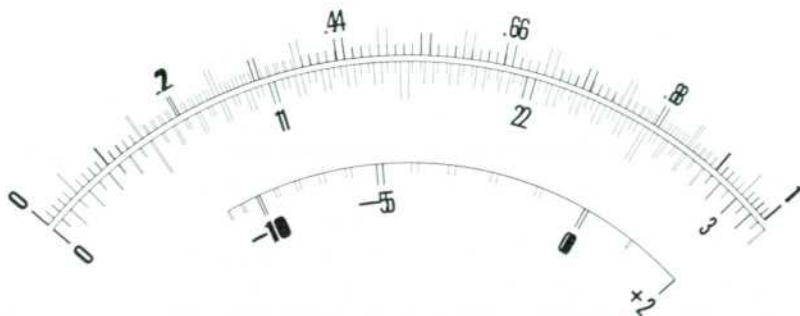


Fig. 4. *Scales for two different meters printed by calibrator on one face. Calibrator sets zero and full scale points to same angular position. Difference in tracking error between these end points is clearly evident. Scale reproduced at 90% of full size.*

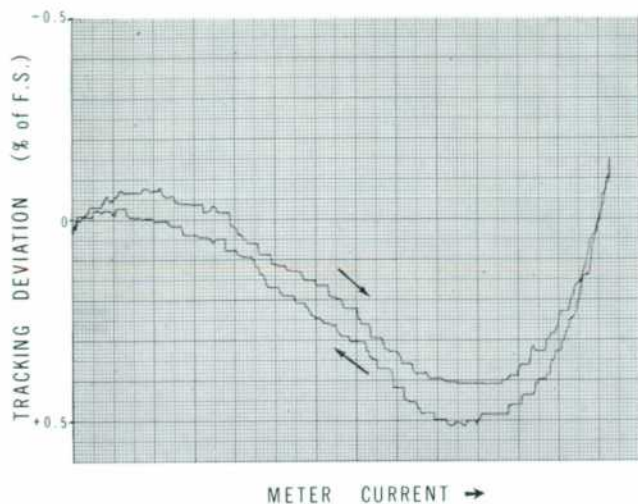


Fig. 5. Typical tracking deviation characteristic for a healthy meter of precision class as obtained with calibrator. Relatively slight opening of curve shows that pivot friction is not excessive, while smoothness of trace indicates freedom from stickiness. Calibrator tailors scale to fit tracking deviation curve of individual meter, thus eliminating indication error from this cause.

viation in the pointer from the linear scale position corresponding to the instantaneous driving current produces an error signal which causes a servo to correct the driving current. At the same time the servo rotates a master scale by the corresponding amount. The servo thus acts to put each point on the master scale at its proper angular position at the time that point is printed. In this way a final scale is produced which is everywhere corrected to the particular deflection characteristic of the meter. Scale and meter are then removed from the calibrator and later assembled in a dust-free, controlled-atmosphere hood.

Since the meters as received may not be properly zero-set, and since the full-scale sensitivity may vary several percent, additional automatic steps were included in the sequence of operation of the calibrator. During an acquisition phase, the machine first electrically picks up the pointer and electrically sets the pointer to the proper zero scale position. It next slews to full-scale position and sets the full-scale current. Then, as the current is reduced from the full-scale value back to the zero-scale value, the scale is printed. In

this way all scales are printed with the proper end-point locations as well as with the proper shape in between. All these operations make use of the same servo system. The entire calibration cycle takes less than one minute so that one machine and one operator can print several hundred meter scales per day. At this rate the cost is comparable to the use of pre-printed scales.

The scales that the calibrator produces are of high quality, as can be seen in the reproduction shown in Fig. 2. Clean, sharp lines are obtained on a matte white surface, and the accuracy of hand calibration is combined with the appearance of a pre-printed scale. A mirror backing is provided for accurate reading. As an indication of the precision of the calibrator, Fig. 2 can be compared with Fig. 3 which shows a scale that has been re-made 5 different times; i.e., the one meter face has been fully processed 5 times by the calibrator. In the illustrations, as in the originals, the two scales are virtually indistinguishable.

As a check on final performance, the calibrated meters are tested for accuracy at all cardinal points after the meter scale has been assembled

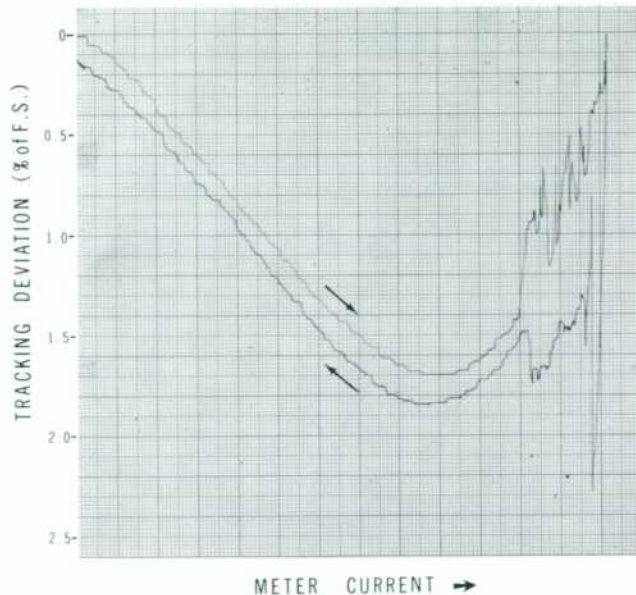


Fig. 6. Tracking deviation characteristic for a meter having slight stickiness at upper part of scale.

onto the movement. These tests are carried out in a standard test set which generates a series of currents having precisely the correct ratios.

#### ADDITIONAL PERFORMANCE IMPROVEMENTS

While the meter calibrator was intended only as a solution to the problem of tracking error, its use has resulted in the virtual elimination of a number of other common meter troubles from production units. This occurs because the calibrator provides very detailed information about other aspects of meter performance. As the servo in the calibrator turns to compensate for the tracking deviation, a potentiometer geared to this same shaft delivers a voltage which is at all times proportional to the deviation. By applying this voltage to one axis of an X - Y recorder and a voltage proportional to the meter current to the other axis, an automatic recording is obtained during calibration of the tracking deviation. A recording obtained in this way of a typical healthy meter is shown in Fig. 5. By inspection of such error records, many troubles which might otherwise pass unnoticed may be discovered and the meters rejected.

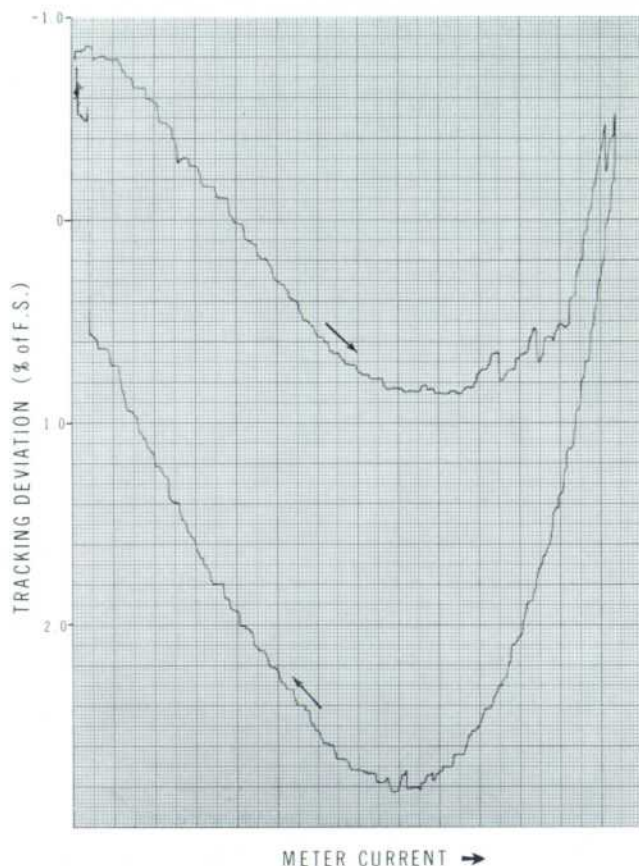


Fig. 7. Tracking deviation characteristic for a meter having excessive pivot friction.

One type of trouble can be automatically rejected by the calibrator. This is the case of severe sticking of the movement. Such sticking will cause the error servo in the calibrator to slew into the limit stop and turn on a "reject" light.

Mild sticking, such as might be caused by defective or tight meter pivots, will produce sharp peaks in the error record or an irregular scalloping of the trace. Such sticking can thus be readily identified.

In type testing meter designs or in further studying some defects, it is often desirable to make a complete error recording for both directions of motion of the pointer. When this is done, it will in general be found that the two traces obtained will not overlap. One common cause for non-overlap is pivot friction, in which case the separation between the two curves is the peak-to-peak error to be ex-

pected in the meter from this cause. If the separation is caused by friction alone, the traces obtained by going from zero to half scale and back will lie atop the first half of those obtained by going from zero to full scale and back. If the two sets differ or if the separation depends on the length of time the current is kept at the full scale value, creep in the meter restoring springs is indicated. Examples of traces obtained from meters with various defects are shown in Figs. 6 and 7.

The advantage of these error recordings in evaluating meter performance lies in the fact that they present on a large scale defects that are difficult to see by eye but which nonetheless jeopardize meter performance. Further, they provide an operational check over the entire meter scale and not just at selected points. It has been through study of these curves that many meter design

improvements have been made, and it is by monitoring these curves for each meter calibrated that *-hp-* is able to provide a 100% quality control inspection of these new improved meters.

#### **-hp- INSTRUMENTS USING NEW METERS**

Servo-calibrated meters are presently being supplied as standard equipment in the following *-hp-* instruments:

Model 400H Vacuum Tube Voltmeter

Model 411A RF Millivoltmeter

Model 412A Vacuum Tube Voltmeter

Model 425A DC Micro Volt-Ammeter

New instruments will be added to this list in the future.

The servo meter calibrator is an example of the application of modern techniques to an old problem. It is, we feel, a significant and overdue contribution to the indicating instrument art. Providing, as it does, improved product accuracy and reliability with no increase in price, it is typical of many contributions *-hp-* has made toward the goal of inexpensive quality in instruments. In some cases the servo-calibrated meters will enable higher accuracy specifications to be established for an instrument. In other cases, although no change in specifications is made, the safety margins within the published specifications will improve and the user will, in fact, receive a more accurate instrument.

#### **ACKNOWLEDGMENT**

Much of the credit for the success of this project belongs to James Triplet who made the initial prototype, to Clifford DeLude and Paul Hauge who, under Paul E. Stoff's direction, worked out the final design, and to Don L. Carmean who, using the calibrator, helped in obtaining improved meter designs.

—Bernard M. Oliver