Weston ENGINEERING NOTES

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In This Issue

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PRESENTING ENGINEERING NOTES

THE Weston Electrical Instrument Corporation's Engineering Laboratories present, as a new publication, WESTON ENGINEERING NOTES. This first edition marks the beginning of a carefully planned program calculated to provide pertinent application engineering information for users of Weston Instruments.

Fifty-eight years of leadership in the manufacture of electrical indicating instruments has resulted in the accumulation of a rich store of experience regarding the application of instruments to their many present uses. Much of this experience has already been passed on to many instrument users by personal contact, lectures, occasional printed material and through engineering service directly with customers in the solving of their measurement problems.

Although company policy calls for sufficient personal contact with application engineers of industry to be of genuine assistance in instrumentation problems it has become increasingly difficult to fully maintain this contact due mainly to the ever widening uses of electrical indicating instruments. To bridge this unavoidable gap is the job of WESTON ENGINEERING NOTES. The program of this new publication has been designed to provide *the greatest good to the greatest number* and, by its instrument application articles, extend the usefulness of the electrical measuring instrument.

We have found that, when called upon for assistance, in many instances our accumulated experience has enabled us to improve the accuracy and reliability of the resulting information and in other instances it has been possible to suggest ways and means to obtain adequate instrumentation at lesser overall expense.

Here is a typical example of what we propose to offer our readers.

Wheatstone Bridge equations are very old but are usually difficult to locate in text books. They are included in this issue, and will enable one to determine the galvanometer current sensitivity required under any given set of bridge conditions. There are many applications where a simple and inexpensive Weston Model 375 Galvanometer will be found adequate as a bridge balance indicator. Again, the most sensitive of suspension instruments may be found lacking in sensitivity. The solution of the galvanometer equation for a given unbalance at a given voltage will give the galvanometer current and, if a readable deflection can be had on that current, the instrument is satisfactory. Thus, the least expensive but adequate galvanometer can be selected.

Extensions of the bridge circuit discussion will appear in subsequent issues and will include the assembly of high voltage bridges, a discussion of the Kelvin Bridge and other special forms and the use of approximate solutions which can be very simple and yet adequate for bridge analysis.

Articles will appear on special rectifier type instruments and thermal instruments of characteristics other than conventional. Discussions will include rectifiers and thermocouples as such. Instrumentation in special electronic circuits will be included at a later date.

The types of articles to be presented will vary. We hope that, like a variety show or oldtime vaudeville, there will always be at least one item of interest to each of our readers in each issue.

—The Editor

THE GALVANOMETER AND THE BRIDGE

The Wheatstone Bridge, useful alike for the measurement of resistance on d-c and a-c as well as capacity and inductance through various classical and recent circuit modifications, is one of the most useful of all measuring systems. Its uses are many, and its ramifications can become very involved.

Perhaps it is those very ramifications that appear to cause many engineers to consider the bridge as a box of tricks to be used in a limited way, rather than as a system of measurement, susceptible to much modification in range of values where required. It is true that the analysis of a six-conductor network is involved, and the pertinent equations are not generally available. They are, therefore, printed here with the hope that they may aid in the understanding and wider use of this versatile method.

Circuit Known in 1833

The network commonly known as the Wheatstone Bridge was actually invented by Mr. S. Hunter Christie, who reported it in the Philosophical Transactions, London, in 1833. Apparently at that time no one recognized its usefulness and attention was called to it at a later date by Sir Charles Wheatstone, after whom it was named.

The bridge is ordinarily drawn in the form shown in Figure 1 with the terminology shown. The several resistance values may be in the form of decade resistances except for the unknown which is connected to the bridge externally; alternatively, a and c (or a and b) may be ratio arms for decimal ratios only, with arm a (or c) a full series of decades with d the unknown.

Galvanometer Selection

Where a bridge is used with an external galvanometer, the value of the current in the galvanometer for a given amount of unbalance or error in the resistance under test is required so that the most suitable galvanometer be purchased or selected for the purpose at hand. Speaking rather generally, galvanometers of higher sensitivity than are needed will be slower in action, will involve more elaborate supports and greater refinement of technique than the less sensitive galvanometers of the pointer type which may be found quite adequate for the purpose.

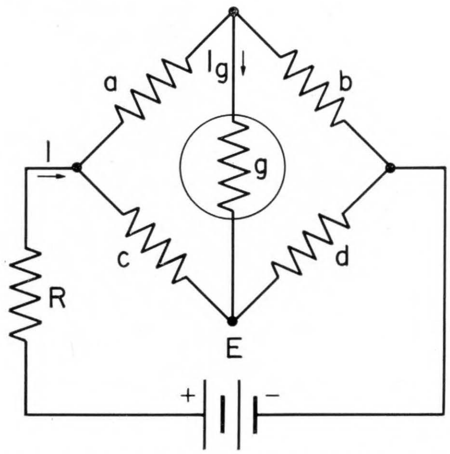
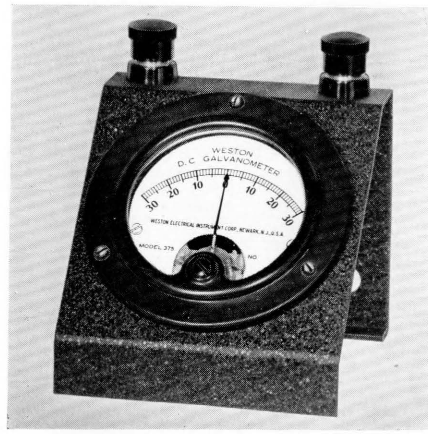


Figure 1—The Conventional Wheatstone Bridge Diagram



The Weston Model 375 Student Galvanometer

The general solution for the galvanometer current follows:

$$I_g = \frac{E(bc-ad)}{R(a+c)(b+d)+Rg(a+b+c+d)+ab(c+d)+cd(a+b)+g(a+b)(c+d)} \qquad (1)$$

where I_g is the galvanometer current in amperes, E the applied battery voltage in volts and g the galvanometer resistance in ohms.

With the battery polarity shown, a positive value of I_g indicates that galvanometer current will flow as indicated.

In many bridge networks the effective series resistance, R is non-existent or can be considered so in view of the very much larger values of resistance in the bridge arms, giving effectively a constant voltage bridge. If R is considered as zero, the equation reduces somewhat and

$$I_g = \frac{E(bc-ad)}{g(a+b)(c+d)+ab(c+d)+cd(a+b)} = \frac{E(bc-ad)}{ab(c+d)+(a+b)(cd+gc+gd)} \qquad (2)$$

Note that the equation is presented in two forms since sometimes one form is easier to solve than the other.

If R is very large so as to dominate the network or, if due to some other circuit condition the current entering the bridge is fixed and known, we have a constant current bridge. The galvanometer current may then be calculated in terms of the current entering the bridge.

$$I_g = \frac{I\,(bc+ad)}{(a+c)(b+d)+g(a+b+c+d)} \qquad (3)$$

The resistance of the bridge presented to the battery is given by

$$Res. = \frac{(a+b)cd+g(a+b)(c+d)+ab(c+d)}{(a+c)(b+d)+g(a+b+c+d)} \qquad (4)$$

This will allow for obtaining the total current taken by the bridge from the battery for any set of conditions.

In the selection of a galvanometer the resulting damping of the galvanometer pointer is usually governed by the resistance in shunt to it and this shunt resistance is given by the equation

$$R_s = \frac{(b+d)ac+bd(a+c)+R(b+d)(a+c)}{(a+b)(c+d)+R(a+b+c+d)} \qquad (5)$$

If R equals zero, or, if the bridge is very nearly balanced, the equation simplifies to

$$R_s = \frac{(b+d)(a+c)}{a+b+c+d} \qquad (6)$$

Throughout the above it will be noted that since we have a linear network, the galvanometer current is in strict proportion to the voltage applied to the bridge or, to the current in the total network.

For the analysis of any bridge network, it is frequently simplest to consider the galvanometer current per volt applied for 1% change in the resistance being measured. Thus, set up the bridge network for a balance at the established resistance to be measured, using the value of the ratio arms which will be selected, and then change d by 1% and solve for the galvanometer current. This will give the galvanometer current per volt, per 1% resistance change. In many instances perceptible deflections are required for 1% error and again for 1/10% error and this will give the current sensitivity needed in the final galvanometer whereby the simplest type can be selected. Conversely, sometimes it is desired to keep the galvanometer deflections on scale and the maximum error for this condition will give the galvanometer current which, in turn, can be used to select a suitable galvanometer.

Impedance Match Principle Best

The best value of galvanometer resistance is obtained on the old impedance match principle. When the bridge is very nearly balanced the best galvanometer resistance is equal to the network resistance or the value above in equation (6). This value is not critical, however, and a galvanometer having a resistance of half or twice the preferred value will have a deflection, other things being equal, of only 13% less than with the best value.

These equations have been derived independently by Mr. W. N. Goodwin, Jr., Vice President in Charge of Engineering and Research, Weston Electrical Instrument Corp. and the writer and checked with the equations to be found in the book "Absolute Measurements in Electricity and Magnetism", by Andrew Gray, MacMillan Co. Ltd., London, where a most complete analysis of a six-conductor network is given.

E. N.—No. 1 —*John H. Miller*

COPPER OXIDE RECTIFIERS AS USED IN MEASURING INSTRUMENTS

The copper oxide rectifier, while dating back only 20 years in terms of practical use, actually is the result of a great deal of study many years ago. Rectification phenomena in copper oxide and selenium layers was reported in 1874 but apparently in those early days it was impossible to rationalize the phenomenon to produce a useful device. Even today we do not know the details of how rectification occurs, although it appears that the interface between the mother copper and the oxide is the layer which allows current to pass freely from the oxide to the copper, and presents a high resistance to reverse flow.

Rectifiers Widely Used

Rectifiers today are used widely with ratings as high as many thousands of amperes for electroplating and electrolytic use generally. They are made as small as the size of a pin head for currents of the order of a few milliamperes and such rectifiers of the copper oxide type are manufactured in large quantity for specific use in instruments.

Figure 1 shows the Weston instrument, rectifier assembly, the stock of 4 discs with their terminals, and typical circuits as used for current and voltage measurement.

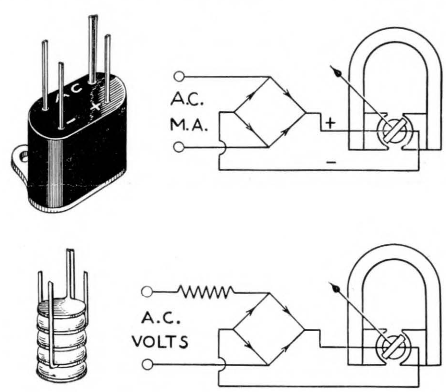


Figure 1—The Rectifier Assembly and Typical Circuits

Copper oxide units are generally preferred to the selenium type for instrument applications simply because of their lower resistance. Selenium rectifiers may be operated up to the order of 10 volts per disc, whereas, copper oxide units are limited to about 2 volts. But since most instrument applications involve loading the rectifiers to only a few hundred millivolts, single copper oxide discs have adequate voltage limits, and the lower resistance means better overall efficiency.

It might be noted here that in 1921 in the Weston Laboratories the first full wave bridge rectifier type instrument was developed for the special laboratory measurement of some low level audio frequency currents. This instrument used molybdenum sulphide rectifiers.

Basic Patent in 1930

There was little commercial requirement at the time for such a combination, however, but in 1925 a rectifier type Weston Model 45 Portable Instrument was developed for commercial application in which carborundum rectifier units were used in the bridge, again for the measurement of currents in audio frequency transformers. A patent application on this combination resulted in patent 1,746,935, issued in February, 1930, as the basic patent on the rectifier instrument as used today.

With the advent of the first disclosure of the copper oxide rectifier in 1927, arrangements were made to use them and the first rectifiers of this type used in commercial instruments were fabricated in furnaces in the Weston plant for this specific application, and were applied to instruments shipped that year.

Discs Vary in Size

The Weston Corporation makes several sizes of discs in order to obtain the best characteristics for a given measurement problem. The d-c characteristics of three of the disc sizes are shown in the curves of Figure 2 where current is plotted against voltage applied.

In the manufacture of the discs a special grade of copper made specifically for rectifiers is obtained and given a lot number. Impurities of the order of a few parts per million, particularly silver, play a rather important part in the final rectifier characteristics. This assigned lot number is carried through all processing to the final assembly and marked on the assembled rectifiers so that all rectifiers of a given lot number have been processed in exactly the same manner from the same material and show similar characteristics.

Discs of the desired size are punched from the special copper and, for each lot, a particular oxidizing and annealing cycle is determined to give the optimum characteristics for use in instruments. From one lot to another the time cycles vary slightly to the end that the final rectifiers vary as little as possible between lots.

Proper Oxidation Important

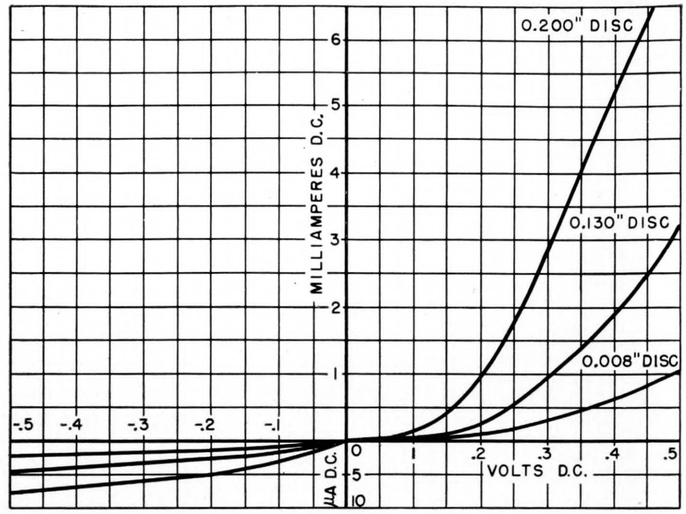
The discs are oxidized in electric furnaces at a temperature near the melting point, passed through annealing procedures, and are quenched. They then pass through a series of acid treatments to clean off the surface black oxide and also to etch out the tiny filaments of mother copper at the edges of the cuprous oxide which, if not removed, tend to lower the back resistance.

Next they are placed in trays under suitable masks and introduced into a vacuum chamber where pure gold is cathode sputtered onto the surface. This gold sputtering procedure, developed in the Weston Laboratories, gives a superior surface to conduct the current into the oxide than the older procedures using graphite and soft metal discs. Gold is applied both to the front and the rear faces of the discs and the terminals with which they are finally associated are also gold plated.

Inspection and Selection Precede Aging

The discs are then individually checked in a fixture to established limits of forward and back current under specific values of applied voltage. The current flowing at any particular voltage, forward or backward, varies in accord with a general distribution law, and about 10% of the discs are rejected in order to maintain as great uniformity as is possible. For special applications discs may be selected with tolerances closer than normal as for rectifiers used in the VU meter.

Figure 2—The Direct Current Characteristics of Weston Copper Oxide Rectifiers



Acceptable discs and terminals are then assembled in the tiny bakelite housing along with the spring arrangement for applying the optimum pressure, and the assembled rectifier is again tested. Rectifiers are aged at an elevated temperature for a period of 30 days to develop long term stability and are checked again before being placed in stock against requirements for use in assembled instruments.

Rectifiers are also used in combinations other than the conventional 4 disc bridge, and assemblies are stocked using the modulator bridge, half wave and half bridge assemblies for special purposes and surge protectors where the curvature of the characteristics serves to protect an instrument against high overloads.

Much Application Data Required

In the application of the rectifier to measuring instruments a great deal of data is needed and, unfortunately, the data must be made available to the instrument designer in terms of so many parameters that it becomes quite unwieldy. As an example, we may consider the design of a 1 ma instrument of rectifier type as commonly used for voltmeters.

To obtain a full scale sensitivity of 1 ma a-c requires a somewhat more sensitive d-c instrument. Since the d-c instrument operates on the average rectified value, but presumably we wish to measure a-c on an rms basis, we are faced immediately with the ratio of the average to the rms value which, with a perfect rectifier and on a sine wave basis, will be 0.9. In other words, with a perfect rectifier the d-c instrument must give full scale deflection on 0.9 ma. Actually the rectifier is not perfect and the output current depends on a great many things. It will vary somewhat with temperature. It will vary with the load resistance, in this case the moving coil of the instrument. It will vary with the frequency of the alternating current applied. Since the current flowing does not follow the voltage because the rectifier is a non-linear resistance, the resulting d-c, a-c current ratio actually varies with the resistance in series with the rectifier itself. From available engineering data and for a moving coil having a resistance of approximately 100 ohms, we find that 0.89 ma d-c will be fed from a 0.2″ diameter rectifier to the instrument with 1 ma a-c applied to it through a moderate resistance and we can so design the d-c instrument mechanism.

Selecting the Rectifier

While this current ratio applies at 1 ma input, it does not apply at lower currents where the ratio is somewhat less, and is a function of the current density in the rectifier. The three curves of Figure 3 show the current ratio of full wave 4 disc rectifier assemblies and it will be observed that at low currents this ratio is highest with the smallest rectifier having the highest current density. The effective resistance of the smaller rectifier is higher, however, and its overlo[redacted] that here engineering judgment comes into play and the rectifier usually selected is one which will handle an overload of several times full scale value.

The data in the curve will thus allow us to lay out the scale for a 1 ma instrument or a very high range voltmeter where the series resistance effectively swamps out the resistance variation of the rectifier and gives a pure current characteristic.

But low voltage instruments, say 10 volts and below, and having a resistance of 10,000 ohms and less, cannot be so treated because the variation in effective resistance of the rectifier is not masked by the series resistance and, accordingly, the current applied to the moving coil of these lower range voltmeters is a function both of the rectifier current ratio and the rectifier resistance. In the practical sense, such voltmeters are hand calibrated against a voltage standard or, if quantities warrant, average data is taken and the scales may then be printed. To show this series resistance effect the scale of a Weston Model 301—1.5 kv instrument is shown in Figure 4 in comparison with that of a 1.5 volt instrument and the contraction of the divisions at the left hand end of the scale in the 1.5 volt instrument will be noticed in comparison with the high voltage scale. This difference is due purely to the increasing rectifier resistance at lower a-c currents reducing the d-c current applied to the mechanism.

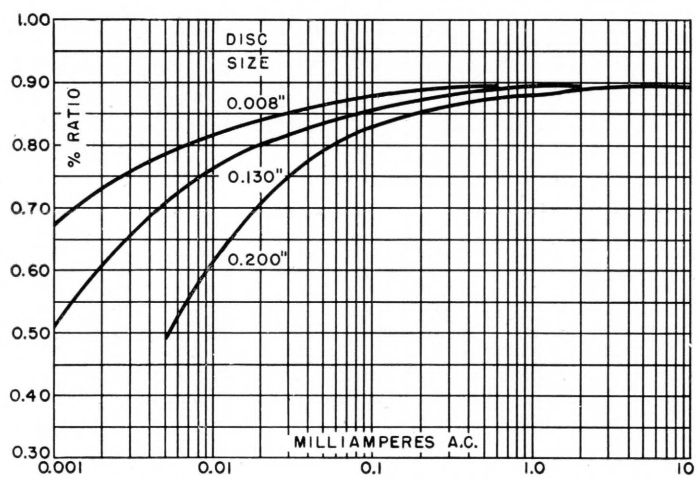


Figure 3—The Direct Current and Alternating Current Ratio of the Weston Copper Oxide Rectifier

The Voltage Doubling Method

The customary meth[redacted] instruments, known as the "voltage doubling method" might be explained here. It was the method used in early experiments and has been standardized in various specifications, such as JAN-I-6. The instrument is placed in parallel with a standard electrodynamometer instrument, a-c voltage applied from a low impedance source such as a variable transformer, and the voltage indicated on the standard recorded for a given deflection on the rectifier type instrument at which the resistance is desired. A decade box is then placed in series with the rectifier instrument and the voltage across the combination as previously measured by the standard electrodynamometer is doubled. The resistance in the decade box is adjusted until the rectifier instrument reading is the same as before. The resistance value indicated on the decade box is then considered as the resistance of the rectifier instrument. Note that this effective resistance will vary with the deflection of the instrument; the resistance of the instrument is usually stated in literature at full scale for voltmeters if not otherwise specified; in DB and VU meters it is usually stated at zero level.

Having the instrument presumably calibrated on some definite frequency, say 60 cycles, sine wave, and at some temperature such as 25 C, a discussion of errors appears next in order.

Wave Form Errors

Wave form errors come into the picture because of the fact that a rectifier instrument reads average value, whereas, we normally read a-c in terms of rms value. The instrument is calibrated to indicate the same as a true rms instrument on 60 cycles sine wave. Any harmonic content will cause an error of greater or lesser degree and as an extreme example let us assume a square or rectangular wave which might be produced by commutating the voltage of a battery. Since the wave has a rectangular shape the rms and average values are the same, whereas, on a sine wave basis there is an 11% difference. As a result the rectifier type instrument as normally calibrated will read 11% high on square topped waves or on d-c.

Mr. W. N. Goodwin Jr., Vice President in Charge of Engineering and Research of the Weston Corporation, in whose name the basic rectifier meter patent was issued, wrote a most interesting article which appeared in "Instruments" magazine for November, 1930, Volume 3, Pages 706-708, entitled "Rectifier Instruments." In this article particular attention was paid to the effects of distorted wave form and from this article a few high spots have been abstracted showing the effect of typical harmonics on the reading of a rectifier meter calibrated to indicate rms value on a sine wave.

In terms of harmonic content, a third harmonic having a magnitude 30% of the fundamental and in phase with it will cause the indication to be 5% high; if 180°

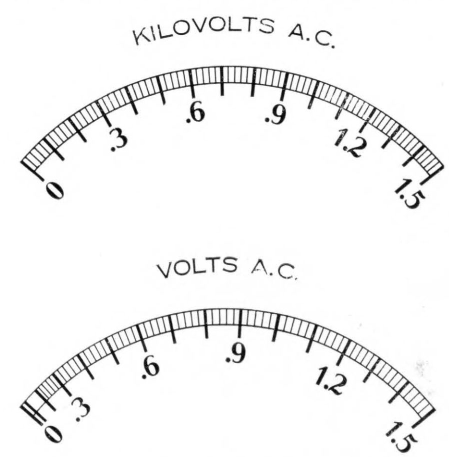


Figure 4—Typical High Voltage and Low Voltage Weston Model 301 Rectifier Type Instrument Scales

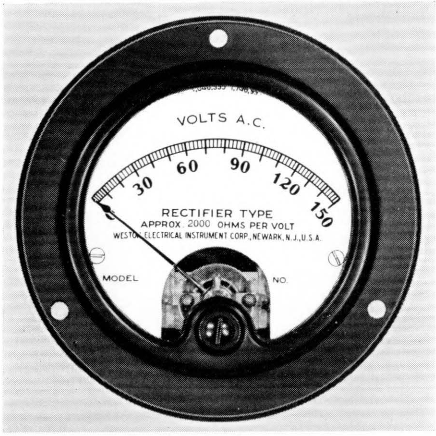
out of phase the instrument will read 14% low. 10% of a fifth harmonic in phase will cause the reading to be about 4% high, whereas, if 180° out of phase, it will be 10% low.

A combination of 30% of third harmonic with 30% fifth harmonic, both in phase, will give a reading 6% high and if both are 180° out of phase the instrument will read 22½% low. Actually these harmonic contents are rather large and the waves resulting very distorted.

On voice frequency and with a completely random distribution of harmonics the error is far less and indications are usually within a few percent of the rms value. Nevertheless, if errors are believed present on a sharply distorted wave, the data given will be representative of what may have occurred, and will indicate the type of problem involved.

Frequency Errors

Frequency errors are due to the capacity in shunt to the rectifying layer of the disc and essentially in parallel with the rectifying layer itself. Obviously, at low frequencies the effect of shunt capacity is small, whereas, at high frequencies it begins to be important in the overall results. Since the resistance of the rectifier is reduced at higher currents, reduction of frequency errors demands operation of the small rectifier at the highest current density consistent with reasonable overload capacity. Conventional instruments as listed in the catalog may read low as much as ½ of 1% per thousand cycles, but such standard instruments have been designed for a rather high overload capacity and with somewhat less concern as to response at the higher frequencies. On the other hand, for special purposes voltmeters have been designed which are substantially flat up to 30 kc and by minor compensation can be made flat, at least for higher voltage ranges, up to 100 kc. Under still more special conditions it is occasionally possible to design for a frequency as high as 1 mc and compensate for a band around that frequency. All such designs, however, involve a



A Weston Model 301 Rectifier Type Instrument

rather complete knowledge of all of the factors involved and it is usually necessary that they be processed by an instrument designer having data applicable to the problem.

Temperature Effects Large

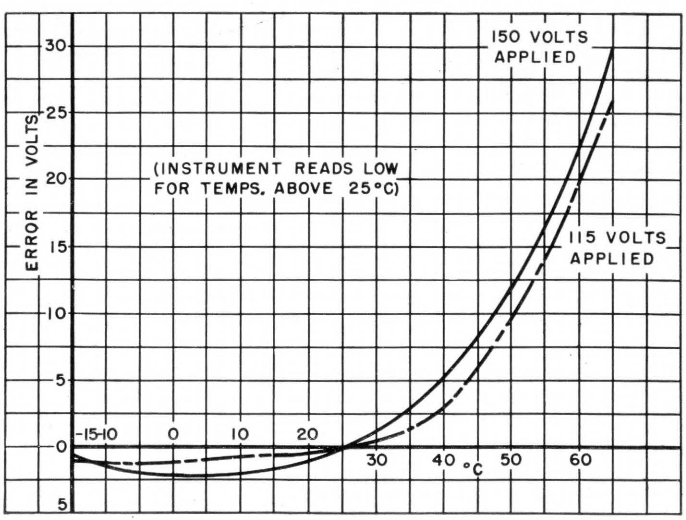
The effects of temperature on rectifier instruments are, unfortunately, rather large and the results of wide temperature changes are likely to be surprising to one not familiar with rectifier instruments. Very broadly, the rectification efficiency of a copper oxide rectifier drops somewhat as the temperature rises but, at the same time, the resistance also reduces. As a result there is a compensation to a degree since the two effects tend to cancel; both effects, however, vary in degree at different temperatures and the result appears to be always a curve, concave downward, when plotting instrument response against temperature.

The change in ratio of d-c fed to the instrument from the rectifier in terms of the a-c current passed through the rectifier network appears to be involved with the leakage current on the reverse half of the wave and the better the rectifier in terms of leakage, the less change in rectifier efficiency with temperature. Very detailed treatments of the discs are required to maintain the lowest possible leakage current and, in turn, to minimize the temperature effect on ratio.

As to the temperature effect of resistance, this can be minimized by using as thin a copper oxide layer as is reasonable since the series resistance is effectively that of the copper oxide itself and has but little to do with the rectifying layer. However, the copper oxide cannot be allowed to be thinner than certain values as otherwise there would be danger of leakage or complete failure and the necessary result is a compromise between the two factors.

Change in ratio with temperature is important in a milliammeter or microammeter. Change in resistance is important where the instrument is in a low voltage circuit and in low range voltmeters. High range voltmeters, by and large, have sufficient series resistance to swamp out the resistance change of the rectifier unit and the net effect is that of ratio change only. Figure 5 shows the change in indication of a 150 volt rectifier type, Weston Model 301 having a sensitivity of 1000 ohms per volt both at full scale and at 115 volts; since the current is different at 115 volts than at full scale the shape of the curve

Figure 5—Temperature Errors for Weston Model 301 A-C Rectifier Type Voltmeter, Range 150 Volts, 1000 Ohms per Volt, with 115 Volts and 150 Volts Applied



changes and here again we have an indication of the complexity of the situation whereby we must necessarily analyze every factor if we are to have full knowledge of the expected results.

Summary

Summarizing the error picture we have the three important effects,

A. Wave form errors.
B. Frequency errors.
C. Temperature errors.

In the last analysis, these errors appear to be the inevitable price paid for the very much higher sensitivity in terms of current and power which we obtain in the rectifier instrument as opposed to the iron vane or thermocouple types. Fortunately, in communications we are more interested in the average level, our temperature does not vary widely, and the wave form is sufficiently random to be suitably summed so that this type of instrument is very useful where the low energy taken from the system is of paramount importance. Rectifier instruments should be applied to systems with intelligence, however, and with a knowledge that some errors may result. In general, if a watt or so is available the conventional iron vane or thermocouple types would be preferred because of their lesser errors and the rectifier type should be used only when the very small extraction of current from the system measured is more important than the errors which arise.

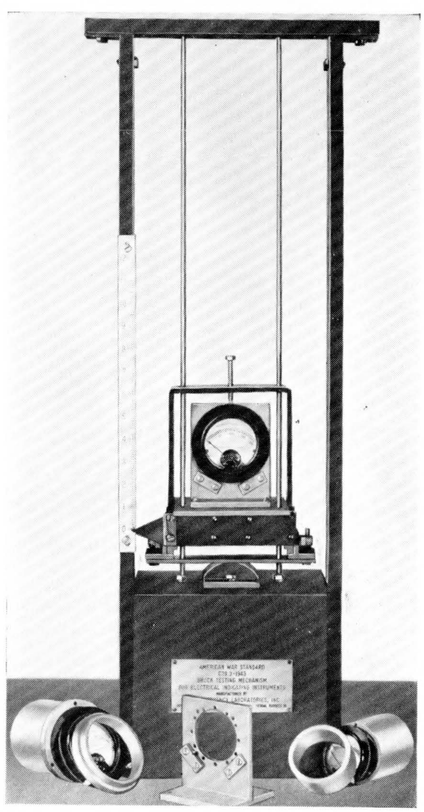
E. N.—No. 2 —*John H. Miller*

SHOCK OR IMPACT TESTING MECHANISMS

Mechanized warfare created many problems for the physicists and engineers. Instruments and other delicate mechanisms were necessary for the operation of airplanes, tanks, ships, etc., but the question was whether these delicate mechanisms would successfully function under the vibration and impacts of engine vibration and gunfire. Most of us can probably recall how, in our undergraduate years, we handled voltmeters and ammeters 'with kid gloves' and milliammeters and microammeters 'with reverential awe.' With little variation these were the same instruments that were to be placed in airplanes, tanks and battleships. Few, if any, instrument designers knew how much vibration or impact an instrument would tolerate and still function satisfactorily and the armed services did not know the amount of vibration present in aircraft, tanks, ships, etc., or what the impact was when volleys were fired from aircraft, salvos from battleships or five inch guns from the decks of submarines.

It would sound nice and scientific if we could have said that instruments on airplanes had to stand so much impact and on battleships so much impact. Unfortunately this was not the case and because of lack of time and the necessity of instruments, the same instruments with minor alterations and mounted on resiliently mounted panels, were tried out and fortunately found satisfactory. It can be truthfully stated that instrument engineers were astonished at the amount of punishment an instrument could really stand and still function. This was largely due to our concept on instruments being altered. Formerly instruments were used under rather ideal conditions and as such the bearing friction had to be infinitesimal. By altering the design of the pivots which resulted in a discernible amount of static friction the instruments functioned perfectly when vibration or impact was present.

As previously stated no one knew how much impact instruments would tolerate and still function satisfactorily. It was therefore apparent that a testing device of some kind was very necessary in order to obtain accurate test data and to set up test standards for the instrument manufacturers and the armed services.



Panel Type Electrical Measuring Instrument Mounted on Movable Carriage of Shock Tester with Dismounted Instrument Support and Accessories Shown

Shock or Impact Testing Mechanisms

The writer has not made any extensive research regarding what may have been done on this problem prior to 1942, although it is believed not very much was done and it can be stated with certainty that no standardized methods of testing meters for impact existed prior to that time.

The National Bureau of Standards and the Weston Electrical Instrument Corp. ran cooperative tests on a number of meters using an impact testing mechanism constructed at the Bureau under the direction of Dr. W. G. Brombacher, Chief of the Aeronautic Instrument Section. A similar type of tester was built at the Weston Laboratories and certain improvements were incorporated.

Originally the Shock Tester was used to determine the effects of impact on instruments equipped with glass "jewels" and sapphire jewels and the use of it was of inestimable value during this jewel development work. The use of the Shock Tester for general tests on instruments was reduced to practice in the Weston Laboratories and a great deal of valuable test data was thus obtained. Cooperative tests with the various branches of the Armed Forces eventually lead to the adoption of the Shock Tester by the American War Standard Committee which included representatives of the various branches of the Army and Navy and instrument manufacturers. The specification entitled "Shock Testing Mechanisms for Electrical Indicating Instruments" was designated as American War Standard C39.3 and later as JAN-S-44.

General Design

The shock testing mechanism resembles a guillotine as can be seen by the illustration. A detailed description of the tester is given in the above specifications, but briefly it consists of a movable carriage on which the instrument to be tested is securely mounted, a stiff calibrated spring resiliently mounted on the underside of the carriage, a heavy base containing an anvil on which the spring strikes and a scale calibrated in inches so that the height to which the carriage is raised can be readily measured. By means of a calibration curve the height to which the carriage must be raised to obtain a certain G value can be ascertained.

Theory of Operation

When the carriage carrying the instrument is raised to a predetermined height potential energy, Wh, is stored up in the carriage and instrument and on falling is transformed into kinetic energy $\frac{1}{2}\frac{wv^2}{g}$. It is assumed that the kinetic energy which equals Wh is totally absorbed by the spring and, therefore, equals $\frac{1}{2}kd^2$ where d equals the maximum deflection of the spring.

$$Wh = \tfrac{1}{2}kd^2 \text{ or } d = \sqrt{\frac{2Wh}{k}}$$

$$\text{Maximum force} = \frac{Wa}{g} = kd \text{ or } a = \frac{kdg}{w} \text{ where}$$

a = the actual maximum acceleration

$$a = \frac{kg}{w}\sqrt{\frac{2wh}{k}} = g\sqrt{\frac{2hk}{w}}$$

$$\text{By definition } G = \frac{a}{g}$$

$$\text{hence } G = \sqrt{\frac{2hk}{w}}$$

where G = the ratio of actual acceleration a to the acceleration due to gravity g expressed in gravity units G as determined by this particular tester.

h = height in inches from which the carriage and instrument under test was dropped.

k = spring constant (pounds per inch deflection).

W = total weight of carriage and instrument in pounds.

Need for Standardization

The committee who drew up the specifications for the above tester realized that if Shock Testers were to produce comparable results in different laboratories it would be necessary that the testers be exact duplicates of each other. For this reason the committee recommended that all of the Shock Testers be built to rigid mechanical specifications and preferably by one manufacturer. The Radio Frequency Laboratories, Boonton, N. J. agreed to build and did build a number of these Shock Testers for the various instrument manufacturers and the armed services. The necessity for this standardization will be apparent from the following paragraph.

Impact or G Value

Force which acts for a very short time is called impact. A steel ball dropped on concrete results in considerably more impact than if the same ball was dropped on a rubber cushion for the simple reason that the rate of deceleration is much greater when the ball strikes the concrete than when it strikes the rubber cushion. This rate of deceleration may be expressed in G units. If the deceleration is at the rate of 32 ft. per sec. per sec., which is the acceleration due to gravity, then G would be equal to one. If the deceleration is at the rate of 320 ft. per sec. per sec. then G would equal 10, etc. In other words the G value is the rate of deceleration expressed in gravity units. However, the damage done to an instrument, or other device, depends on how the deceleration takes place. For example if the deceleration on the tester took place in only 0.001 or 0.002 inch it is very likely that the instrument or device under test would yield that much and hence the internal and external decelerations would be entirely different. On the other extreme if the G value is obtained by means of centrifugal force then the deceleration would be equivalent to a static loading condition. These two illustrations represent extremes but it is quite obvious that any impact or shock tester must be between these two extremes. For example on the Shock Tester as per JAN-S-44 the spring deflection at 100 G is approximately 0.10 inch and with this much spring deflection it is perfectly reasonable to expect the internal and external decelerations to be very nearly the same.

Although the Shock Tester was developed and recommended for testing electrical indicating instruments its use has been extended to the testing of small power relays, miscellaneous aviation instruments and radio components, and from our experience it will always be a useful tool in locating the weakest link in the inherent design of small mechanisms.

E. N.—No. 3 —*A. T. Williams*

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