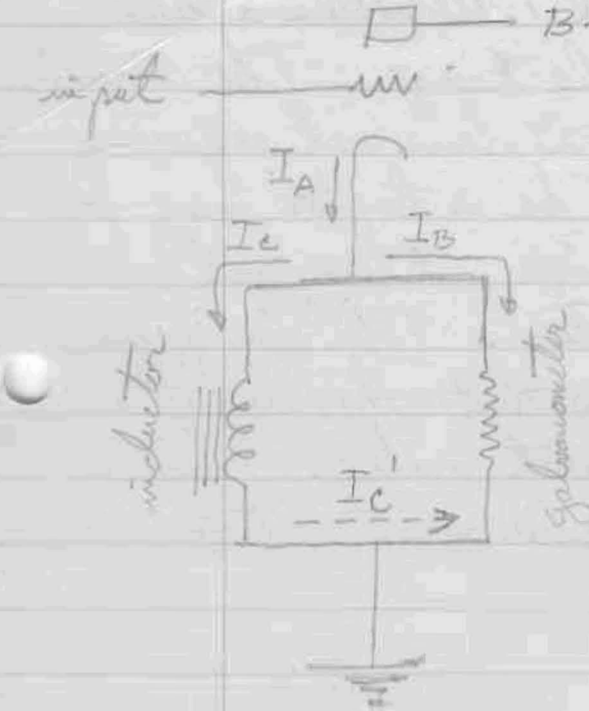
30 July 58

Recorder Circuit.

The pen is sluggish when required to move only part way across scale. See correspondence with Esterline-Angus. This may be partially overcome by connecting an inductor across the galvanometer element as shown. When I_A decreases abruptly because the atmospherics stop, I_B will decrease in proportion because the galvanometer is mostly resistance. However I_c cannot decrease in proportion because of inductance. Thus it must flow as I_c' in a reverse direction thru the galvanometer. The net effect is that I_B reduces faster in proportion than I_A. This causes galvanometer to go down more quickly and decreases the damping of instrument.



It would be best if this effect were small for large changes of I_a and large for small changes of I_a. Such can be accomplished by making the inductor saturate to very low inductance values at large I_c. While this will give good performance for small changes near bottom of scale and large changes across full scale, the performance will be poor for small changes near half to full scale. To give uniformly good performance for small changes anywhere from bottom to top scale, the inductance must remain high for all values of I_c

(over)

Most useful readings are between bottom and half scale. Thus a compromise can probably be made where the inductance is maximum at zero I_c; half inductance at half I_c; and less than one tenth inductance at maximum I_c.

The ratio of I_c to I_B is a matter of experiment. However somewhere between 1:5 and 1:10 seems a likely compromise if the inductance is made large. The Brush galvanometer has a resistance of 1500 ohms and requires 32 volts across it for full scale. The inductor may be two UTC type S-23 chokes in series. This will give about 3.2 ma maximum thru inductor. The air gaps should be reduced or eliminated so that the inductance at 1.6 ma is about half the zero current value. This will give very large initial inductance plus a saturation perhaps near 3.2 ma.

Perhaps by using a permalloy core the inductance can be made to decrease very rapidly near maximum I_c. Actually the energy of inductance is $\frac{1}{2}L\overset{\Delta}{I}{}_c^{2}$. The energy discharged into galvanometer is $\frac{1}{2}L(\Delta I_c)^2$. When ΔI_c is small, then L should be large. When ΔI_c is large, then L should be small. This requirement holds over entire range of I_c. Obviously no simple choke can carry out this requirement. Probably only a compromise can be secured as given at top of sheet.

See price quotation at back of papers.

THE ESTERLINE-ANGUS COMPANY, INC.
Manufacturers of Electrical Instruments
INDIANAPOLIS 6, INDIANA
P. O. Box 596

July 24, 1958
AIR MAIL

MR. GROTE REBER,
General Delivery,
Wailuku,
Maui, HAWAII.

Dear Mr. Reber:

With reference to your letter of July 19, it is true that the damping of our DC milliammeters does vary to a certain extent with the degree of deflection across the scale. This is illustrated by attached curve C-426, which was developed from actual performance of an instrument under the conditions shown. It will be noted that the curves are not completely consistent, which most likely means that there were minor variations in friction of one kind or another during the test period, or that minor errors were introduced when transferring the original instrument curves to the tracing from which the prints were made.

It is believed that since in a recording instrument of the direct writing type various frictional forces are an appreciable percentage of the deflecting force, it would be difficult to establish the exact reasons for the change in damping characteristics at different points on the scale, or to calculate and predict the exact performance. From curve C-426 it is apparent that the changes in performance at different deflections are relatively small, and of such magnitude that in comparison with the accuracy obtainable from the instrument, they can probably be ignored.

Attached is a copy of an article by Prof. Graybill titled "Frequency Response of Recording Instruments" which appeared in the June 1948 issue of ELECTRICAL ENGINEERING. There is also a copy of an article from the November 1953 issue of the Sanborn publication THE RIGHT ANGLE regarding the accuracy of oscillographic records. While these two articles may not be directly concerned with your problem, they are closely allied to it, and we hope will prove of interest to you.

Discussions of damping characteristics of indicating instruments will be found in most text books on electrical measurements, such as that found on pages

"The Meter With a Record" — FOR OVER 50 YEARS

108-115 of ELECTRICAL MEASUREMENTS by Dr. Harris of the National Bureau of Standards and George Washington University. The book is published by John Wiley & Sons. Also there is Chapter 3 of the 1952 Edition of Volume I of ELECTRICAL MEASURING INSTRUMENTS by Drysdale, Jolley & Tagg, published by Wiley.

One of these references states in effect - "Since --- friction --- has a constant value for a given combination of spring and bearing (and presumably pen point on paper) it will be apparent that the effect of friction in bringing the system to rest is relatively greater for small than for large changes in deflection."

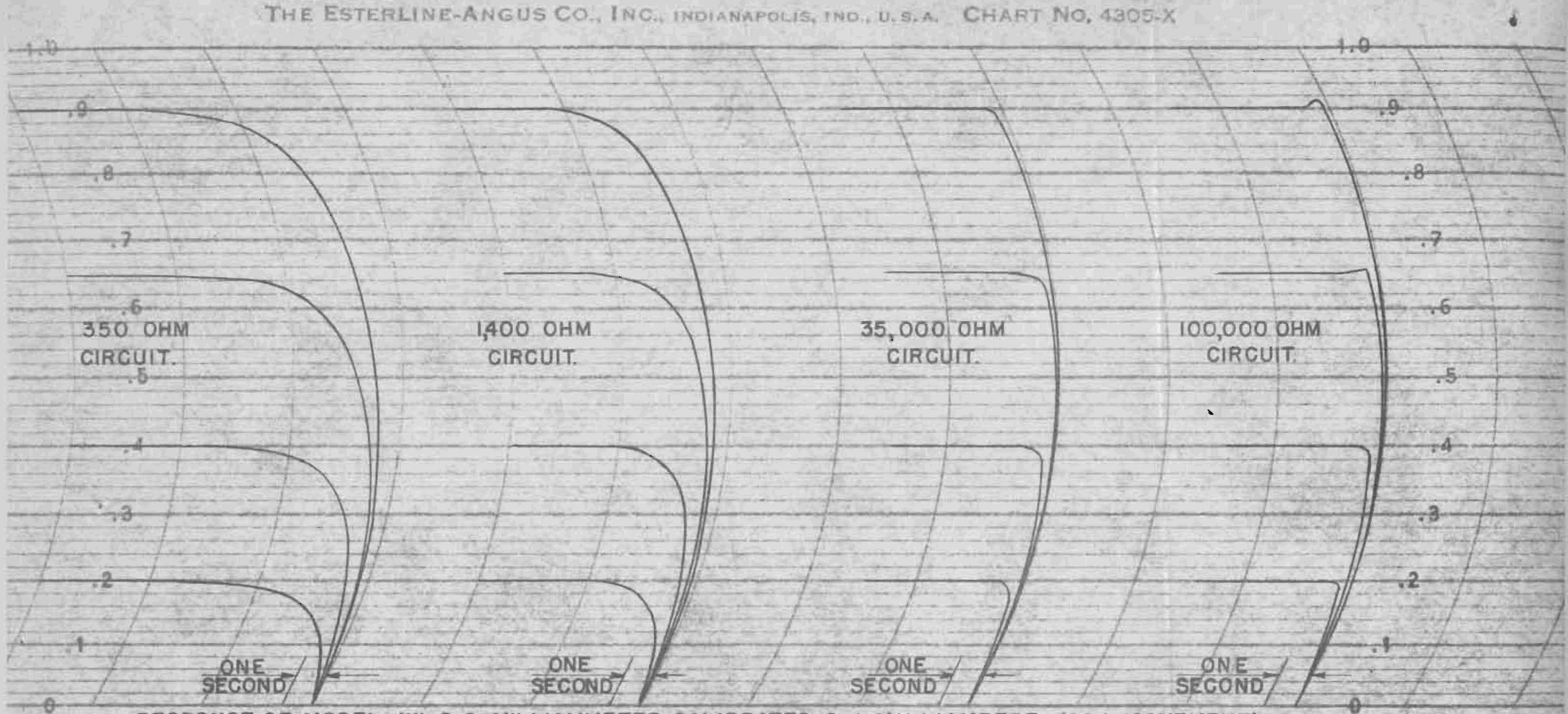
Yours very truly,

THE ESTERLINE-ANGUS CO., INC.

James Gall

James Gall

JG:dr



RESPONSE OF MODEL AW D.C. MILLIAMMETER CALIBRATED 0-1 MILLIAMPERE (424 MOVEMENT)
IN CIRCUITS OF VARIOUS RESISTANCES. CHART SPEED, 12 INCHES PER MINUTE.

JAN. 7, 1948

NO. C-426

Frequency Response of Recording Instruments

TROY D. GRAYBEAL
MEMBER AIEE

THE DYNAMICS of common types of instrument movements have been studied a great deal, but information dealing with this subject has not been available readily in a form suitable for application work. The behavior of most instruments can be defined by a second order differential equation. In this case the frequency response characteristics can be expressed in terms of the undamped natural frequency and the relative damping. Curves can be plotted in terms of these two parameters to provide a simple and direct method of predicting the magnitudes of instrument errors so that one may decide whether a particular system is satisfactory for a given application, and if so by what margin. The frequency of the signal is expressed as a fraction of the undamped natural frequency of the instrument in order that the curves be applicable universally.

The relative damping and undamped natural frequency may be obtained by simple test methods based upon a-c steady-state or transient response tests, or they may be computed from the physical characteristics of the instrument if sufficient design data are available. Transient tests usually require less complicated testing equipment, and for this reason methods based upon transient tests usually are preferable. The values of undamped natural frequency and relative damping obtained by test methods are subject to some error from imperfections of the instrument, notably friction between the pen and the chart, as well as from the limit of accuracy of making measurements on chart records. The former is not serious in a well-designed properly adjusted instrument, and the latter may be minimized by the choice of a suitable chart speed.

If an instrument is to record accurately at high speed, it must have a high undamped natural frequency, and it must be damped properly. The undamped natural frequency depends upon the inertia of the instrument movement and upon the spring constant of the restoring spring. Once an instrument is built, there is little that can be done by the user of the instrument to increase the undamped natural frequency. The relative damping, on the other hand, is usually to some degree under his control. Electric instruments of the D'Arsonval type and some oscillographs obtain a considerable part of their damping effect from the electric circuit in which the instrument is connected. Thus the relative damping may be changed by changing the resistance of the electric circuit as seen from the instrument terminals. In other instruments damping is introduced by air vanes or by submerging the element in oil. In these instances the damping may be changed by adjusting the air vanes or by the use of an oil of different viscosity.

The frequency response of an instrument is critically dependent upon the relative damping, and for this reason proper damping should be secured before other means are tried for increasing the frequency response. For maximum response, the damping should be somewhat less than 0.7, the exact value being determined by the maximum error that can be permitted in the record obtained. A loss of ten to one or more in frequency response easily can result from improper damping.

It is possible to increase the frequency response of an instrument beyond that obtainable with optimum damping, either by making modifications in the instrument movement to increase the undamped natural frequency, or for D'Arsonval-type movements, by the use of coupling networks between the coil circuit of the instrument and the network where the measurement is to be made. Both these methods present a greater burden by the instrument on the network in which the measurement is to be made. The upper limit that can be achieved practically, depends upon the maximum permissible coil current that will not damage the coil of the instrument from overheating.

At the present time there are available commercially several types of servo-actuated recorders mostly in the form of self-balancing potentiometers. These instruments require a relatively small error signal, of the order of one per cent to five per cent of full scale, to produce maximum velocity of the recording pen. The time required for the pen to move from one end of the chart to the other under this condition is a standard specification of such instruments, and can be used for estimating the maximum frequency, or minimum period, which the instrument will record accurately. Curves (based upon signals of sinusoidal wave form, and neglecting any errors introduced by lags in the servomechanism of the instrument) may be drawn that show the relationship between the minimum period and the peak-to-peak amplitude of a recorded signal for accurate response of a servo-actuated instrument in terms of time required for full scale movement of the recording pen. As long as the period of the signal being recorded is not less than that indicated by these curves, the error in the record obtained at any point will not be greater than the proportional range of the servomechanism. Results obtained from this simplified approach are sufficiently accurate for application work, as one wishes to know the order of magnitude of the minimum period the instrument will record accurately, rather than the value of this minimum period to a high degree of accuracy. When recording irregular wave forms, the fundamental limitation is the maximum rate of change of the signal being recorded expressed in chart divisions per second, and not the fact that the signal contains harmonics as is the case with most other types of instruments.

Digest of paper 48-172, "Frequency Response Characteristics of Recording Instruments," recommended by the AIEE instruments and measurements committee and approved by the AIEE technical program committee for presentation at the AIEE North Eastern District meeting, New Haven, Conn., April 28–30, 1948. Scheduled for publication in AIEE *TRANSACTIONS*, volume 67, 1948.

Troy D. Graybeal is assistant professor of electrical engineering at the University of California, Berkeley, Calif.

Factors Affecting Accuracy of Oscillographic Records

ARTHUR [illegible]
[illegible]
[illegible]

2. Errors as a Function of Dynamic Conditions in Oscillographic Recordings

The previous article (The Right Angle, *August, 1953*) described the class of errors which are a function of static conditions, and showed how these static errors can arise and how they may be measured. These static errors do *not* depend on the rate of change of the input signal. Those which *do* depend on the rate of change are known as the *dynamic* errors, and will be considered in this article.

The characteristics of a linear recording system can be completely specified by the relative magnitude and phase of input and output sine wave test signals. Since the magnitude and phase vary with frequency, these characteristics must be given as a pair of curves: a curve of relative magnitude with respect to frequency and the curve of phase shift with respect to frequency.

By having these two curves, it is theoretically possible to predict ahead of time exactly how any complex wave would be distorted. This would be done by first analyzing the input signal into its equivalent sine wave components, then determining the corresponding output signal for each of these sine wave components (from the amplitude and phase curves of the system), and then finally combining these output sine wave components to show the resulting output signal.

For practical applications this procedure is usually too unwieldy to be of much use. In spite of this, it is possible to state the requirements of the theoretically ideal recording system. These are: (1) constant amplitude response for all frequencies from zero to infinity, and (2) a phase shift which is either zero for all frequencies, or which is proportional to frequency. The slope of the phase shift[1] curve equals the "time delay" of the recording system, a term which will be illustrated later with respect to the recording of a pulse type signal.

No physically realizable system can meet these requirements, and the problem then becomes one of trying to correlate departure from ideal with the distortion which will result in a particular recording. Such a correlation is still difficult to make.

Square Wave or Step Voltage Test

Another approach to this problem of testing the ability of a recording system to accurately reproduce varying quantities is by way of the "square wave" or "step voltage" response.

The step voltage test is based upon the idea that *no* physically realizable recording system can reproduce such a wave form without distortion *but the degree and kind of distortion is immediately apparent.* It will be recalled that the sine wave test signal *couldn't* be distorted, and that the recording system performance had to be represented in terms of a pair of curves.

The "step" function contains within itself two features which encompass the two extremes of speed and slowness in signal variation. The initial rise represents infinite speed, while the subsequent step represents absolute zero variation with time. It would seem therefore, that a study of the way in which the rise and step are recorded would give some clue as to the way in which the rapidly and slowly varying components of an actual input signal would be recorded.

The manner in which the step is recorded is described in terms of three figures. These are the "rise time," the percentage of "overshoot," and the slope of the recorded step following the initial rise.

A typical response to a step input is shown in Figure 1 below.

In this figure, and in the remainder of this discussion the rise time will be defined on the basis of the straight line which most closely approximates the actual response to the vertical rise of the input step.

One of the most commonly used recording instruments is the D'Arsonval moving coil galvanometer, and it is of interest to examine the response of this instrument as described in terms of both sine wave and step voltage test signals.

Figure 2 shows the frequency response curve of such a galvanometer for two adjustments of its damping. The frequency scale is plotted in terms of the ratio of the frequency to the undamped natural frequency, of the instrument. Please note that the curve which corresponds to the critically damped condition seems to have a rather restricted flat response range. In fact, if one examines the formula from which the plot is

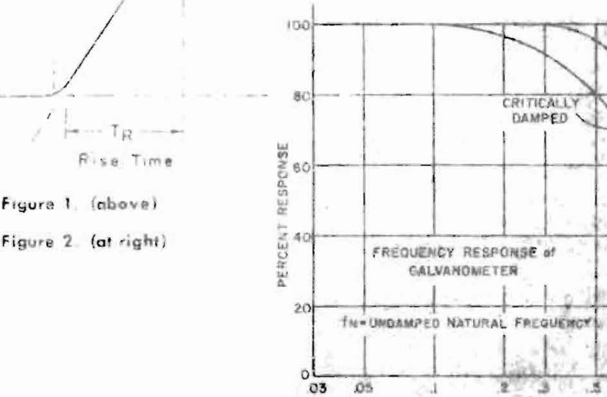


Figure 1. (above)

Figure 2. (at right)

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[1] For a typical Sanborn 150 amplifier and direct writing galvanometer combination, the "rise time" is about 8 milliseconds, and the "delay time" is about 4 milliseconds. Differences between units will be less than 10% of these figures.

made, it appears that 100% response is obtained *only* at zero cycles, and that the response starts to droop immediately thereafter. When the natural frequency is reached, the sensitivity has fallen to 50% of the D.C. value.

As the damping is reduced, the range of "flat" response is increased. If the damping is reduced below a value which is 71% of "critical," the response curve will actually rise *above* the 100% level. Further reduction in damping will give the response curve a hump which grows in magnitude and slides over towards the natural frequency. In other words the damping cannot be reduced below the 71% of "critical level" without raising the response above 100%.

Looking at the two curves shown in Figure 2, how would one rate them on a comparative basis? If one defines frequency range on the basis of, say, 90% response as tolerable performance, then the 71% damping curve extends to a frequency of 68% of the natural frequency of the galvanometer, while the critically damped curve reaches that response at 33% of the natural frequency. On that basis, one would reach the conclusion that the 71% damping curve is twice as good as the critically damped curve. If, on the other hand one were more generous with the tolerance and allowed the upper frequency limit to be defined as the frequency for 50% response, then the critically damped curve reaches that point at the undamped natural frequency, while the 71% curve holds out to 1.3 times the natural frequency giving a band width ratio here of 1.3 to one.

As will be shown later, the second one of these comparisons gives a much more realistic appraisal of the relative merits of the two adjustments.

Now let us look at the response of the same galvanometer to a step voltage as seen in Figure 3.

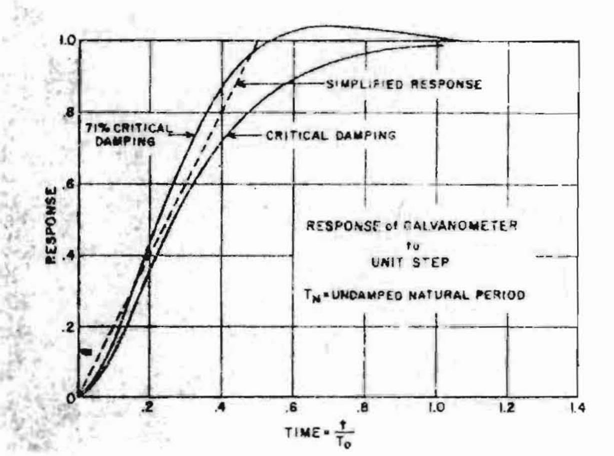

Figure 3.

For the critically damped condition, the response to a step voltage approaches the final value asymptotically and never exceeds it. Any reduction of the damping below that value will allow the response to exceed the final value momentarily, and, in fact, the criterion for critical damping is that a reduction will allow overshoot. At 71% of critical, the adjustment which gave the best looking frequency response curve, there is a slight overshoot of 4% of the final deflection.

The 71% curve can be very closely approximated by a straight line which reaches the final response value at a time equal to *one half* the undamped period of the galvanometer, and this can be taken as the rise time of the instrument. For the critically damped case, it is a little harder to fit a straight line approximation to the curve, but a reasonable one will yield a rise time figure which is *not much greater* than half the galvanometer period.

Recording Complex Signals

When one is recording a complex signal of arbitrary wave form, one is dealing with neither a sine wave nor a step function. The points of greatest interest in such a record are usually the peaks, or points where the trace changes direction. These points are also the ones most difficult for the recording system to trace out.

A sample of such a wave form is shown below.

Figure 4.

It is seen that the peaks and points of inflection look like the vertices of triangles, and, in fact, it would not require too great an effort of the imagination to think of the wave as the sum of a series of triangular components, just as Fourier analyzed a wave into a series of sinusoidal components.

This brings us to the point of calculating the response of a recording system to a triangular impulse.

A triangle can be considered to be the sum of three sloping straight lines as follows

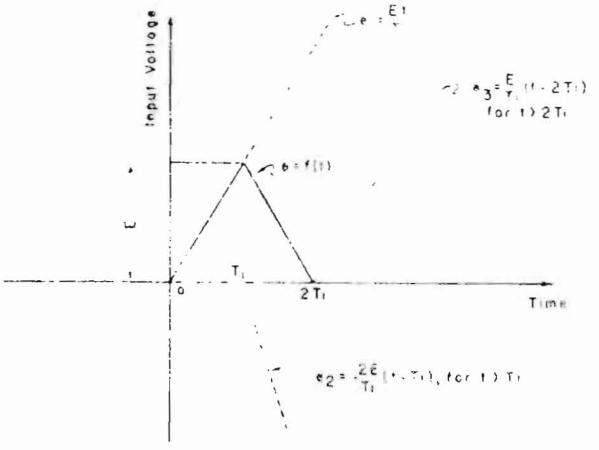

Figure 5. Straight line synthesis of isosceles triangle

The response of a recording system to a voltage which is represented by a sloping line can be calculated; and if the response of the system to a step voltage can be approximated by a broken line as shown in Figure 6, the calculation is simple.

The response to a sloping straight line then is as shown in Figure 7.

It turns out that the time displacement between input and response is equal to one half the rise time.

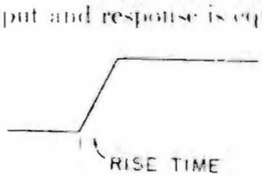

Figure 6

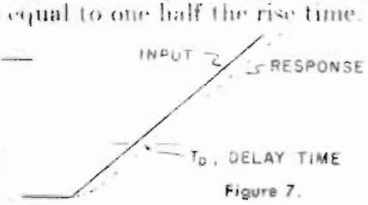

Figure 7.

Furthermore after a time equal to the delay time, the recorder is making an exact copy of the sloping straight line. In other words it was the corner which was distorted, because the corner represented a point of rapid change of slope of the input signal.

Now if this calculation is carried out for each of the three sloping lines which makes up the triangle, and the results are added together the recorded triangular pulse is reassembled.

The results are shown in Figure 8, for a triangle whose base width is four times the rise time of the recording system.

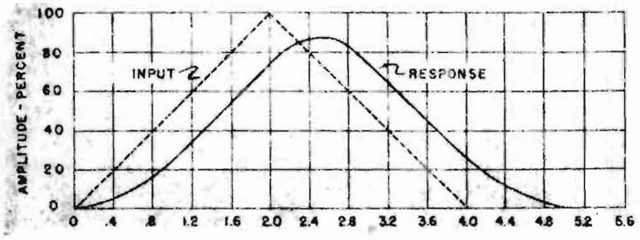

Figure 8. Reproduction of triangular impulse by recording system with idealized step function response

It is seen that the input triangular pulse is fairly well reproduced, but is shifted in time by an amount equal to the "delay time." The most serious distortion which the triangular pulse suffered is a loss in true amplitude.

As the base width of the triangular pulse is reduced, the loss in amplitude becomes greater, until, when the base of the triangle becomes only twice the rise time of the recording system, the recorded pulse bears only a slight resemblance to the original.

If we limit ourselves to isosceles triangular pulses whose bases are at least twice the rise time of the recording system, then a simple formula can be deduced which gives the percentage by which the recorded pulse misses the true amplitude of the original pulse

$$\text{PERCENT LOSS} = \frac{50\ \text{TR}}{\text{BASE WIDTH OF TRIANGLE}}$$

Applying this formula to the narrowest triangle for which it is valid, the error is seen to be 25 percent.

Furthermore, if the error is to be less than 1%, then the triangular pulse must be wider than 50 rise times.

Thus, if we are dealing with a recording system whose rise time is .01 seconds, and whose static accuracy is of the order of one percent, then a similar order of accuracy for dynamic conditions will be achieved only for signals whose rate of change is so slow that a time interval of about .2 seconds is required for the signal to move from one level to another.

These figures are a little pessimistic because the razor sharp vertex of the triangular test pulse does not occur in actual physical phenomena, but the order of magnitude of the errors which can be encountered are close to those calculated above.

These facts are often not fully realized, and the plots of relatively rapidly varying quantities are read to extreme tolerances simply because the chart happens to be a wide one, or because static calibrations have been made to such close tolerances, even though the finite response time of the recording system has provided errors five or ten times as great as the supposed accuracy of the measurement.

To summarize this discussion:

A. The ability of a recording system to properly record rapidly varying signals of complex wave form is most easily and directly judged in terms of the "rise time" of the system as measured from the response to a "step" or square wave input.

B. The conventional frequency response curve can vary widely in shape with only small differences appearing in the square wave response.

C. The "delay time," which represents the interval by which the recorded trace is shifted bodily is equal to one half the "rise time."

D. The rate of variation of input signals must be quite slow in relation to the rise time in order to insure good accuracy in the resulting record.

In the next issue Dr. Miller will discuss Differential Input Circuits.

Effect of Controls on Position of Stylus

There are six controls which can affect the position of the stylus on the chart, when using the combination of a D. C. Amplifier Model 67-300 and the D. C. Preamplifier Model 67-400.

The baseline position is so important in all types of oscillographic recording, that the function of each control is outlined below showing how it can affect the baseline position.

Starting at the output and working backward towards the input signal, these are (refer to Schematics 67-400-C1 and 67-300-C1):

a. **The centering control R316.** This is supposed to be the official adjustment for establishing the baseline position unless the DC preamplifier balancing control R425 is made to take over this function.

b. **The smooth gain (sensitivity) control R315.** If there is no input to the main DC amplifiers, and if that amplifier is properly balanced, then there is no potential difference between the plates of V301, and this gain control can then be turned without any motion of the stylus.

c. **The main DC amplifier balance control, R354.** This is the control used to guarantee the equality of potentials at the plates of V301 but its adjustment must be made with no input to the main DC amplifier, otherwise it will compensate not only for inequalities in the V301 circuits, but also for the input signal. To make sure of this, R354 should be adjusted with the attenuator at OFF.

d. **The step attenuator.** If there is no input from the DC preamplifier, no appreciable grid current in the grid circuits of V301 and no leakage from high

19th July 1958
General Delivery
Wailuku, Maui, Hawaii

Esterline-Angus Company
P.O. Box 596
Indianapolis 6, Indiana

Att: Engineering Department

Gentlemen:

This letter is an inquiry about the damping of your instruments. Assume first, the circuit constants are adjusted to give critical damping at full scale deflection. When the current is instantaneously started (or stopped) the pen moves entirely across the chart and reaches the final deflection without any overshoot. The pen moves 90% of its total deflection in time T_1. With the same circuit constants apply only enough current to give half scale deflection. The pen moves across half scale without any overshoot. It moves 90% of itstotal deflection in time T_2 which is greater than T_1. Thus the instrument is overdamped.

Now change the circuit constants so that the instrument is just critically damped for half scale deflection. Then, without changing the circuit constants, apply sufficient current to provide full scale deflection. The pen whips across the chart to a few percent beyond full scale and settles back with perhaps a further small oscillation. Obviously the instrument is now underdamped.

From these observations it appears that the damping of the pen varies with the deflection. Please advise me what information you have on the subject, or where I may secure a discussion in the literature.

Very truly yours,

Grote Reber

Grote Reber

QUOTATION

ELECTRONIC TRANSFORMER CO., INC.
70 WASHINGTON STREET
BROOKLYN 1, NEW YORK
Telephone: MAin 5-6123

8564

Date 8/25/58
ETC Quotation No. 58-8564
Your Inquiry No. 8/9/58
Delivery 5 to 6 wks after receipt of order
Terms 1/10 N/30
F.O.B. BKLYN NY
Packing

TO: MR. GROTE REBER
GENERAL DELIVERY
WAILUKU, MAUI, HAWAII

Gentlemen:

In reply to your inquiry of 8/9/58 we are pleased to submit our quotation as follows:

Quantity	Type No.	Description	Unit Price
4		SATURATING REACTORS L greater than 1000 hy. at o.m.a. approx. 300 hy. at 1.6 ma. D.C.R 10,000 ohms This unit has been referred to us by Burnell and Co. 10 Pelham Parkway Pelham Manor, New York	35.00

This Quotation shall be void unless accepted within 30 days from date hereof. Prices stated herein are based on rates of wages and costs of material in effect on the date of this quotation.

The prices quoted herein do not include any sales tax, duties, excise or similar taxes now in effect or which may hereafter be imposed by the Federal or State Government, and made applicable to the merchandise and/or the sale thereof included in this quotation. All such taxes imposed will be added as a separate item on the invoice, except upon presentation of proper exemption certificates.

CONDITIONS PRINTED ON THE REVERSE SIDE OF THIS SHEET CONSTITUTE PART OF THIS QUOTATION.

ELECTRONIC TRANSFORMER CO., INC.

By: Hal Borgen Jr.

SALES MANAGER
(Title)

9th August 1958
General Delivery
Wailuku, Maui, Hawaii

Burnell & Co., Inc.
10 Pelham Parkway
Pelham Manor, New York

Att: Mr. L. Schwartz

Gentlemen:

I wish to purchase four saturating reactors with the following performance.

Inductance: Greater than 1000 hry at 0.0ma.
Approximately 300 hry at 1.6ma.
Less than 10 hry at 3.2ma

D.C. Resistance: 10,000 ohms

Size and weight are no object. An open frame mounting is satisfactory. The circuit will have frequency components up to 100 cycles. Perhaps some kind of a permalloy core will be needed.

Please advise details giving size, weight, price and delivery schedule of whatever you suggest. If a hundred to one inductance ratio is not possible please indicate what can be achieved.

Very truly yours,

Grote Reber

Grote Reber

brush INSTRUMENTS
Division of Clevite Corporation
3405 PERKINS AVENUE • CLEVELAND 14 OHIO • TELEPHONE: ENDICOTT 1-3315

August 28, 1958

Mr. Grote Reber
General Delivery
Wailuku, Maui
HAWAII

Dear Mr. Reber:

This is in response to your letter of July 19 regarding damping of our oscillographs.

The effects which you have observed and described in your letter are due primarily to the friction of the pen on the chart paper. Most of the damping of our oscillographs is provided by the coil resistance. This is reflected into the mechanical vibrating system by virtue of the motion of the coil in the magnetic field. The mechanical reflection of this resistance is very linear. Added to this, however, is the non-linear resistance of the pen tip friction.

It is very difficult to provide quantitative information because of the complex nature of the mechanical system, and particularly the complex nature of the friction element. The mechanical system is described by Shaper in the March 1946 issue of ELECTRONICS Magazine. There is no simple way of accounting for the friction because of its non-linear nature and the fact that it is strongly influenced by chart velocity.

Somewhat over a year ago we introduced an improved penmotor in our full line of oscillographs. This has about 2½ times the stiffness of our older penmotors, and thus greatly reduces the influence of friction. With the newer equipment properly adjusted for optimum pen pressure, it is difficult to detect the variation in damping described in your letter. I am enclosing some literature on this new equipment.

Very truly yours,

JP Arndt

J. P. Arndt
Assistant to the General Manager

JPA:js
Encl.
No enclosure

CLEVITE

19th July 1958
General Delivery
Wailuku, Maui, Hawaii

Brush Electronics Co.
3405 Perkins Avenue
Cleveland 14, Ohio

Att: Engineering Department

Gentlemen:

This letter is an inquiry about the damping of your instruments. Assume first, the circuit constants are adjusted to give critical damping at full scale deflection. When the current is instantaneously started or stopped the pen moves entirely across the chart and reaches the final deflection without any overshoot. The pen moves 90% of its total deflection in time T_1. With the same circuit constants apply only enough current to give half scale deflection. The pen moves across half scale without any overshoot. It moves 90% of its total deflection in time T_2 which is greater than T_1. Thus the instrument is overdamped.

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From these observations, it appears that the damping of the pen varies with the deflection. Please advise me what information you have on the subject, or where I may secure a discussion in the literature.

Very truly yours,

Grote Reber

Grote Reber

MANUFACTURING
& SALES

RESEARCH &
DEVELOPMENT

Century Electronics & Instruments, Inc.

1333 NORTH UTICA — PHONE LUTHER 4-7111
TULSA 10. OKLAHOMA. U. S. A.

March 3, 1959

Associated University
P.O. Box 2
Green Bank, W. Va.

Attn: Grote Reber

Dear Sir:

Thank you for your expression of interest in our instrumentation products. The descriptive literature you requested is enclosed.

Should you desire additional information after reviewing this literature, please do not hesitate to call on us.

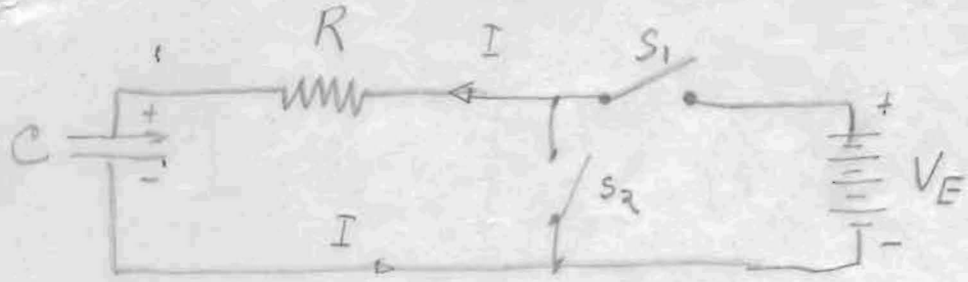
We appreciate this opportunity to acquaint you with Century products and look forward to serving your instrumentation requirements in the near future.

Very truly yours,

CENTURY ELECTRONICS & INSTRUMENTS, INC.

D. R. Weichert,
Sales Administrator

Enclosure:
Product:



V_c = instantaneous voltage across condenser
Q = " charge on condenser

$V_c = Q/C$

~~$I_0 = V_E/R$~~

~~$I = (V_E/R)e^{-t/RC} = I_0 e^{-t/RC}$~~

$Q = C V_E (1 - e^{-t/RC})$

$V_c = \frac{Q}{C} = V_E(1 - e^{-t/RC})$

$\frac{V_c}{V_E} = (1 - e^{-t/RC})$

$1 - \frac{V_c}{V_E} = \frac{1}{e^{t/RC}} = \frac{V_E - V_c}{V_E}$

$\frac{1}{1 - \frac{V_c}{V_E}} = e^{t/RC} = \frac{V_E}{V_E - V_c}$

$\frac{t}{RC} = \log_e \frac{V_E}{V_E - V_c}$

$t = RC \log_e \frac{V_E}{V_E - V_c}$

9 July 1958

Charging of a condenser

V_c/V_E	$\log_e(-)$
.5	.69
.8	1.38
.9	2.30
.95	3.00
.99	4.60
.995	5.30
.999	6.90

V_c arrives within 10% of final value in 2.3 RC
V_c " " 1% " " " " 4.6 "
V_c " " 0.1% " " " " 6.9 RC