A NEW METHOD FOR DIGITAL COMPENSATION OF A.C. BRIDGES

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1. Introduction

The rapid development of industrial production has compelled electric measurement engineering to meet increased requirements. The demand for high-speed, accurate, automatic measurements is encountered in measuring of the most diverse electric quantities. A large group of measurement methods

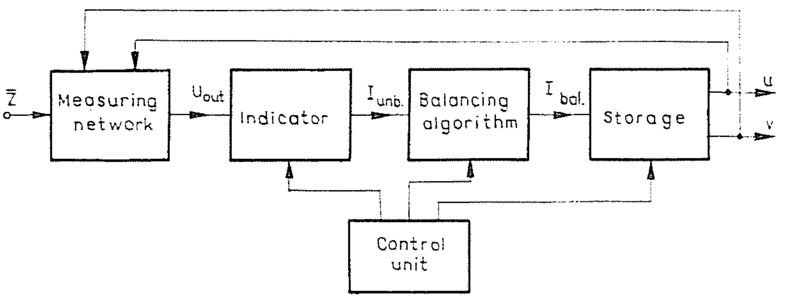

Fig. 1. The general scheme of precision balanced measurements

satisfying the requirements of precision is represented by the balanced measuring networks. A precondition of these measurement methods is to create a compensated network state. High-speed automatic compensation can be achieved if the compensation algorithm is realized by a digital automatic equipment.

The paper examines how to increase the rate of high precision A.C. measurements. Such precision measurements are possible with measuring networks, where the value of the output voltage or current is zeroed.

The general scheme of examined measuring methods is shown in Fig. 1. The complex signal $\bar{Z}$ is compared with the feed-back u and v parameters and from this the measuring network — e.g. a bridge — generates the error voltage U_{out}. This voltage is processed by the indicator channel and on the output the indicator gives the information ($I_{unb.}$) about unbalancing of the network. This information yields the information for balancing ($I_{bal.}$) by the compensation algorithm. On the basis of information for balancing the content of storage is modified. This storage memorifies the values of u and v parameters. From the output of storage the u and v balancing parameters are fed back to the network, and thereby the changes of the balancing parameters modify the measuring network. In such a way it is possible to do precision measurement, even if the indicator and compensation algorithm are not accurate enough. The periodic operation of the studied system is guaranteed by a control unit.

The paper touches upon the problems of the measuring network, the indicator and the compensation algorithm.

2. Balancing properties of A.C. measuring systems

The essential feature of balanced measurement is to endeavour to zero the voltage between two points of the measuring network (or zero current in one of its branches). Let us have U_{out} as the voltage to be zeroed. With the network build-up known, the complex function

$$U_{out} = \Psi(U_g; Z_1 \ldots Z_n; Z_x) \tag{1}$$

may be given, where U_g is the generator voltage, $Z_1 \ldots Z_n$ are the network impedances, and Z_x is the complex vector to be measured. In the state of compensation $U_{out} = 0$ whereby, from the complex equation

$$0 = \Psi(U_g; Z_1 \ldots Z_n; Z_x) \tag{2}$$

it is possible to determine Z_x, if U_g; $Z_1 \ldots Z_n$ are known.

The state of compensation is achieved by the appropriate modification of the two balancing parameters. Information for this modification is obtained by the evaluation of the output U_{out} with respect to the compensation algorithm. The method of evaluation, that is, the compensation algorithm, may be different in character. The well-known amplitude minimization and phase-sensitive indicating algorithms are the simplest ones.

The evaluation process following a given algorithm can be clearly traced along the balancing trajectory of the measuring network. The balancing trajectory indicates the correlation between the output voltage and the balancing parameters u, v by giving the

$$\begin{aligned} U_{out} &= x + jy = \Psi(U_g \ldots u_i, v), \\ U_{out} &= x + jy = \Psi(U_g \ldots u, v_k) \end{aligned} \tag{3}$$

curve sets of function

$$U_{out} = \Psi(U_g \ldots u, v). \tag{4}$$

Figs 2 and 3 present two typical trajectories. In addition to these trajectories, a measuring network is also illustrated in each figure (Maxwell—Wien bridge, capacity measuring network with ideal current comparator) to represent the given trajectories. Analyzing the compensation process by means of the trajectory leads to the qualitative conclusion that an increased curvature of the trajectory makes compensation much more difficult. For example, the

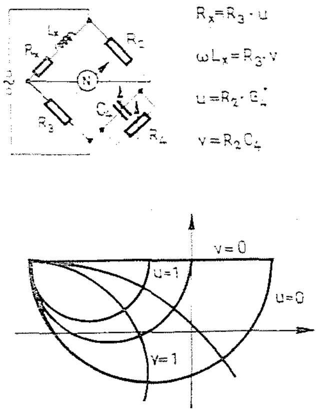

Fig. 2. Balancing trajectory of Maxwell—Wien bridge

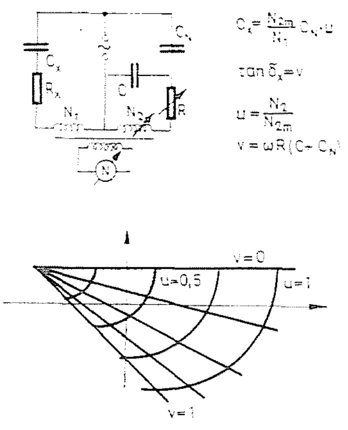

Fig. 3. Balancing trajectory of ideal current comparator faradmeter network

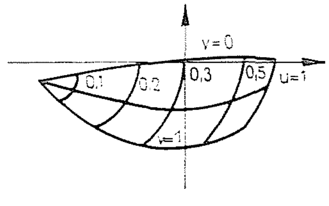

Fig. 4. Balancing trajectory of current comparator faradmeter network

trajectory of the current comparator faradmeter network illustrated in Fig. 4 which, due to the nonlinear magnetic properties of the core in the comparator, exhibits increased distortion as compared to the ideal, and less favourable compensation characteristics than the ideal trajectory shown in Fig. 3.

If the compensation characteristics of a given trajectory are to be described by an index, this is excellently feasible by the determination of the redundance of error signal U_{out}. If the compensation algorithm is ideal, that is, if it makes use of all the informations on the error, then the error redundance of U_{out} represents that of the complete measurement as well. An increased redundance means unequivocally a much more difficult compensability.

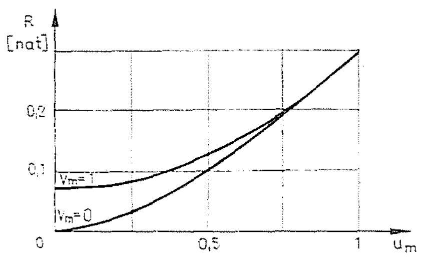

Fig. 5. Trajectory-redundance of Maxwell—Wien bridge

Determination of the redundance requires the following initial assumptions:

quantization of the balancing parameters u, v is uniform and, since this quantization is made best use of by a uniform probability distribution, be the quantity to be measured uniformly distributed in the ranges $0 \leq u \leq u_m$; $0 \leq v \leq v_m$,

the maximum information content of the U_{out} is given by the uniform distribution above region A, where A is the transformation of the quantity range to be measured into $U_{out} = x + jy$.

On the basis of these assumptions the redundance will be

$$R = \ln A - H(U, V) = \frac{1}{u_m v_m} \int_0^{v_m} \int_0^{u_m} \ln |J[\psi]| \, du dv \text{ [nat]} \tag{5}$$

where $J[\psi]$ is the Jacobi determinant of function $(x, y) = \psi(u, v)$. Thus relation (5) was used to determine the trajectory redundances of Figs 2 and 3 in function of u_m, v_m. The redundance of the Maxwell—Wien bridge is shown in Fig. 5, while that of the ideal current comparator faradmeter network in Fig. 6. It is interesting to compare the redundance of the distorted trajectory plotted in Fig. 4 ($R_1 \approx 1$ nat) with that of the ideal trajectory, for $v_m = 1$ ($R_2 = 0.39$ nat). Inequality $R_1 > R_2$ reflects the less favourable compensation characteristics of the trajectory presented in Fig. 4.

Figs 5 and 6 reveal that, in the usual u_m, v_m measurement ranges, the trajectory redundance is small. Thus, where only this information loss would impede measurement, its redundance would still be negligible even at a significant trajectory curvature. In practice, however, the information content of the error signal cannot be totally transferred to the compensation — there is no way to realise a too complicated compensation algorithm. Consequently, a minor redundance expressing small curvature will considerably increase the compensation time.

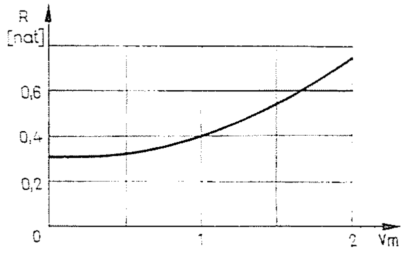

Fig. 6. Trajectory-redundance of the ideal current comparator faradmeter network

3. Information collected from the error signal

An important part of the balanced measuring systems is the indicator channel which is to supply information on the complex error signal of the network. This is why the present chapter will briefly discuss the measuring problems of the sinusoidal signal, as a quantity characterized by a complex vector.

The problem is how to measure the parameters A and B of a

$$y(t) = A \sin \omega t + B \cos \omega t$$

signal. Of the many feasible measurement techniques, here only two practically important methods will be described.

a) *Measurement of instantaneous values*

Signal $y(t)$ is measured at two times ($t_1 = 0$ and $t_2 = t$). The results are:

$$y_1 = B$$
$$y_2 = A \sin \omega t + B \cos \omega t \tag{6}$$

Eqs (6) permit to determine the redundance of probability variables (y_1, y_2) transformed from uniform distribution (A, B):

$$R = \ln (1 + |\text{cotan}\, \omega t|) . \tag{7}$$

The variation of R in the function of ωt is illustrated in Fig. 7. It is easy to see that the most convenient measurement ($\omega t = \pi/2$) is redundance-free. Choosing $\omega t < \pi/2$, the redundance will increase, the evaluation of measurement will be much more complicated (see Eqs (6)), and these disadvantages will only be compensated by the reduced measuring time.

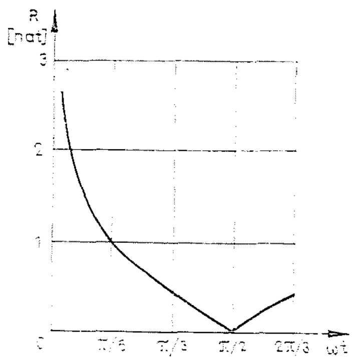

Fig. 7. Redundance of instantaneous value measurement

b) *Integrating measurement*

The integration of variable $y(t)$ is measured in two intervals (0—t_1 and t_1—t_2). By substituting $\omega t = x$, we get the following results:

$$T_1 = \int_0^{x_1} y(x)\mathrm{d}x = A(1 - \cos x_1) + B \sin x_1 .$$

$$T_2 = \int_{x_1}^{x_2} y(x)\mathrm{d}x = A(\cos x_1 - \cos x_2) + B(\sin x_2 - \sin x_1) , \tag{8}$$

wherefrom the redundance of transformation:

$$R = \ln \frac{(1 - \cos x_1 + |\sin x_1|)\,(|\cos x_1 - \cos x_2| + |\sin x_2 - \sin x_1|)}{|\sin x_2 - \sin x_1 - \sin (x_2 - x_1)|} . \tag{9}$$

Fig. 8 illustrates the levels of redundancy function. It is seen that zero redundance is produced by $x_1 = 0$; $x_2 = \pi$. Since, however, $x_1 = 0$, this would require an instantaneous value measurement and an integrating measurement, and could not satisfy therefore our condition. The most convenient measurement is by selecting $x_1 = \pi/2$; $x_2 = \pi$ as then the redundancy is ln 2, and the evaluation of the measurement is not too complicated, either.[1]

More important problem is the effect of the indicator-filter. The fundamental harmonic of the error signal must certainly be rejected in order to make precision measurement feasible. Due to the upper harmonic content of the generator, the nonlinearity of the impedance to be measured, and the not quite frequency-independent compensability of the network, near to the compensation the error voltage will have a considerable upper harmonic content.

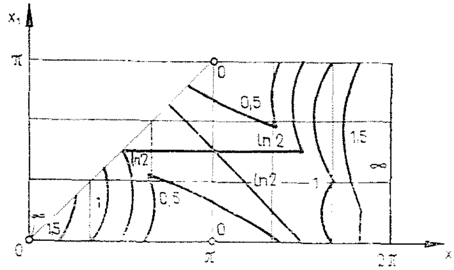

Fig. 8. Redundance of integrating measurement

tent. With respect to the compensation time, the rejection effect increasing measurement time is most important since, after the measurement of the error and the subsequent interference, the new state will be brought about through a transient one. The question is what time interval is necessary before the next measurement.

The problem outlined above will be analyzed by using a simplified model but the results thus obtained may be considered as qualitatively identical to those of a full-value test.

The simplified model is as follows:

The error signal is a direct voltage, and the filter is a single-capacity proportional element with time constant τ. The direct voltage error is measured approximately and, corresponding to the measurement result, the network will be interferred with at $t = 0$, whereby the error will be reduced to a known extent. The transient function of the error is

$$y(t) = y_1 + \mathbf{Y}(t) \tag{10}$$

where y_1 is the residual output, to be determined by the next measurement, and $\mathbf{Y}(t)$ is the transient rendered by switching off the variable of known $\mathbf{Y}_0$ magnitude. Since nothing but $y(t)$ can be measured, the transinformation

[1] Note. This measuring method, integrating for one quarter period after the other, is like the usual, over-lapping half-periodical measuring — from the viewpoint of the information processing.

between $y(t)$ and y_1 must be determined. This transinformation is limited by two factors: uncertainty of the transfer characteristics of the filter (here in τ), and the noise of indication.

First the effect of time constant uncertainty will be studied. Since

$\mathrm{Y}(t) = \mathrm{Y}_0\, e^{-\frac{t}{\tau_0}}$, the entropy of $\mathrm{Y}(t)$ is

$$H[Y(t)] \approx H\left(\frac{\tau}{\tau_0}\right) + \ln Y_0 - \frac{t}{\tau_0} + \ln \frac{t}{\tau_0},$$

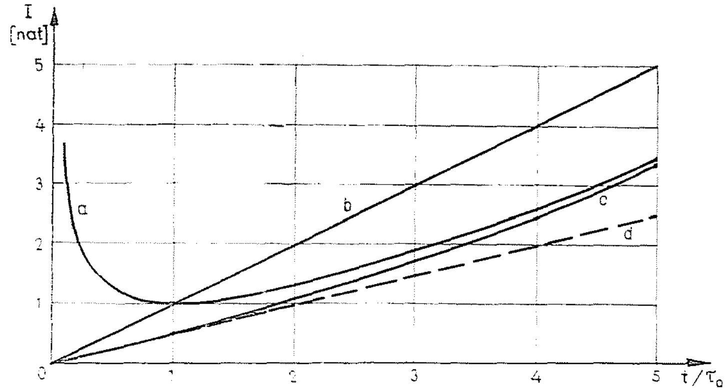

Fig. 9. Information content of measurement vs. holding time. a) uncertainty of time constant: b) noise of indicator; c) resultant transinformation; d) information content of practical measurement

where τ_0 is the mean value of τ, and the uncertainty is small as compared to this mean. The transinformation sought for will be

$$I_1(y;y_1) \approx H(y_1) - \ln Y_0 - H\frac{\tau}{\tau_0} + \frac{t}{\tau_0} - \ln\frac{t}{\tau_0}. \tag{11}$$

The term $\frac{t}{\tau_0} - \ln \frac{t}{\tau_0}$ in Eq. (11) vs. $\frac{t}{\tau_0}$ is shown by curve *a* in Fig. 9.

The noise of indication will also limit the transinformation between y and y_1. The indicator noise is proportional to the quantity to be measured and, therefore, if the random variable describing the noise is z, then

$$y(t) = \left(y_1 + Y_0 e^{-\frac{t}{\tau_0}}\right)(1 + z), \tag{12}$$

wherefrom at a fixed y_1, the conditional entropy will be:

$$H(y|y_1) = H(z) + \ln \left| y_1 + e\, Y_0^{-\frac{t}{\tau_0}} \right| .$$

In practice, among the two uncertainties, the latter one will be dominant only, thus y_1 can be neglected. In according to the average conditional entropy:

$$H(y|Y_1) = H(z) + \ln Y_0 - \frac{t}{\tau_0}$$

and the transinformation:

$$I_2(y; y_1) \approx H(y_1) - \ln Y_0 - H(z) + \frac{t}{\tau_0} . \tag{13}$$

In case of a correct synthesis, the transinformation I_2 will be zero at $\left(\frac{t}{\tau_0}\right) = 0$, which means that all the previously available information has been made use of during intervention. Thus:

$$I_2(y; y_1) \approx \frac{t}{\tau_0} , \tag{14}$$

as shown by curve b in Fig. 9.

The joint effect of I_1; I_2 leads to a resultant transinformation. For $H\left(\frac{t}{\tau_0}\right) \approx H(z)$ this resultant will develop according to curve c in Fig. 9. It is clearly seen that the resultant curve has a slight upward-bend. It follows that increasing the information quantity of the measurement, the time requirement grows relatively slower. Accordingly, the speed of compensation will slightly increase if, within a single measurement, more information is collected on the error signal.

In practice, however, this time gain is not utilized since the measurement employs the following method:

Wait until the deviation of $y(t)$ from the steady-state y_1 appears to assume a negligible Δ value, and then it may be said that y_1 had been measured with a Δ quantum accuracy. Thus the information obtained will read:

$$H^*(y_1) = \ln \frac{y_{1\max}}{Y_0\, e^{-\frac{t}{\tau_0}}} .$$

Time t is chosen so as to make the Δ quantum measurement accuracy satisfied even at transient of the maximum amplitude:

$$H^*(y_1) = \ln \frac{y_{1\max}}{Y_{0\max}\, e^{-\frac{t}{\tau_0}}} = \ln \frac{y_{1m}}{Y_{0m}} + \frac{t}{\tau_0} . \tag{15}$$

At the same time, under correct synthesis conditions, the information $H^*(y_1)$ just obtained will correspond to the information content $\ln \frac{Y_{0m}}{y_{1m}}$ of the previous measurement (the latter made possible the reduction of the rate Y_{0m} to y_{1m}), thus we get

$$H^*(y_1) = \ln \frac{Y_{0m}}{y_{1m}} = \ln \frac{y_{1m}}{Y_{0m}} + \frac{t}{\tau_0} ,$$

wherefrom

$$H^*(y_1) = \frac{1}{2} \cdot \frac{t}{\tau_0} . \tag{16}$$

Eq. (16) reveals that for the measurement method applied the information obtained is proportional to the time. Curve d in Fig. 9 illustrates this relation.

4. Characteristics of compensation algorithms

We have to analyze the information about U_{out} given by the indicator channel, that is to select the information for compensating. This analysis is completed on the basis of the compensation algorithm.

There may be various compensation algorithms, but their fundamental characteristic is the iterative nature. This is a matter of course, because the measurement of output signal at a given u and v setting gives but few information, generally much less than that to be obtained on the quantity to be measured.

The iterative nature of the balancing process means the achievement of the compensation state (u, v) through the sequence (u_1, v_1), (u_2, v_2) ... (u_n, v_n).

Now let us examine the iterative sequences of the two simplest compensation algorithms (for the sake of simplicity redundance-free trajectory is assumed).

Fig. 10 *a* presents the successive steps of the amplitude minimizing algorithm: $(0, 0)$, $(u_1, 0)$, (u_1, v_1), (u_2, v_1), . . . With a convergence angle γ of the trajectory, we get

$$u_n = u + v \cos_\gamma^{2n-1} ,$$
$$v_n = v - v \cos_\gamma^{2n} . \tag{17}$$

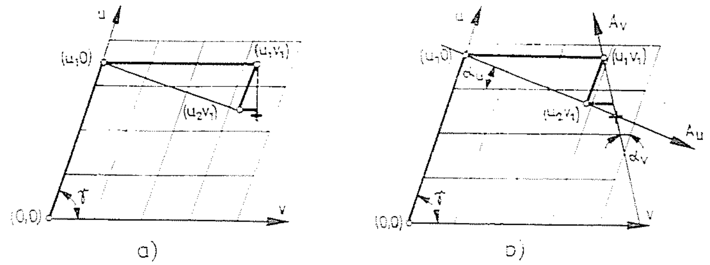

Fig. 10. a) Compensation by amplitude minimization; b) Compensation by phase sensitive indication

Fig. 10 *b* presents the phase sensitive compensation of a γ convergence angle trajectory with given A_u, A_v reference axes. The iteration steps are

$$u_n = u + v k_u^n k_v^{n-1} ,$$
$$v_n = v - v k_u^n k_v^n , \tag{18}$$

where

$$k_u = \frac{\sin \alpha_u}{\sin (\alpha_u + \gamma)} , \qquad k_v = \frac{\sin \alpha_v}{\sin (\alpha_v + \gamma)} .$$

Introducing expressions $\cos \gamma = k$ and $k_u k_v = k$ will make (17) and (18) alike

$$u_n = u + v k^{2n-1} ,$$
$$v_n = v - v k^{2n} , \tag{19}$$

and

$$u_n = u + v k^{2n-1} \sqrt{\frac{k_u}{k_v}} ,$$
$$v_n = v - v k^{2n} . \tag{20}$$

Thus the problems of two algorithm types are also similar which makes possible to deal only with the minimization of the amplitude hereafter. Eqs (19) revealed that there exists an unequivocal correlation between (u, v) and (u_n, v_n), whereby the transinformation thereon may be made infinite. In practice, however, this transinformation is limited since

the trajectory (in the present case: k) is not quite accurately known, and

the points of iteration are found only with some uncertainty because of the finite sensitivity of the indicator.

Now the effect of these two uncertainty factors on the measurement of v will be studied. An analysis of the measurement of u would render qualitatively identical results.

a) *The uncertainty effect of the trajectory*

Starting from

$$v_n = v - vk^{2n}$$

the transinformation between v and v_n must be determined, when the entropy $H(K)$ defining the uncertainty of k is known.

With a fixed v, the entropy of v_n will be

$$H(V_n|v) = H(K) + \int f(k) \ln \left|\frac{\partial V_n}{\partial k}\right| dk \approx H(K) + \ln 2n + \ln v + (2n - 1) \ln k_0 ,$$

where k_0 represents the mean value of k. The average conditional entropy is, on the other hand, assuming a uniform distribution for v in the region $(0, v_m)$:

$$H(V_n|V) = \int f(v) H(V_n|v) dv = H(K) + \ln 2n + (2n - 1) \ln k_0 + \ln v_m - 1 .$$

In case of a small standard deviation, a good approximation is given by

$$H(V_n) \approx \ln v_m .$$

whereby the transinformation will read:

$$I(V, V_n) = H(V_n) - H(V_n|V) \approx 1 - \ln 2n - (2n - 1) \ln k_0 - H(K) . \quad (21)$$

Fig. 11 illustrates $I + H(K)$ vs. n, at a parameter of $\cos \gamma = k_0$.

b) *The effect of uncertain compensation*

If the next point of the compensation process is found accurately, then the new deviation will be $\cos \gamma$-times the previous one (see Fig. 10a). Due to the imperfect indication, however, finding the point of iteration will involve an error of instability. The latter depends on a random variable ξ characteristic of the indicator, and on the residual error voltage proportional to $\sin\gamma$. Thereby, in course of a compensation step, the reduction of deviation is described by the random variable $(\cos\gamma + \xi \sin\gamma)$. It follows that the iteration steps will also be represented by random variables:

$$\begin{aligned} u_n &= u + v \prod_{i=1}^{2n-1} (\cos\gamma + \xi_i \sin\gamma)\,, \\ v_n &= v - v \prod_{i=1}^{2n} (\cos\gamma + \xi_i \sin\gamma)\,. \end{aligned} \tag{22}$$

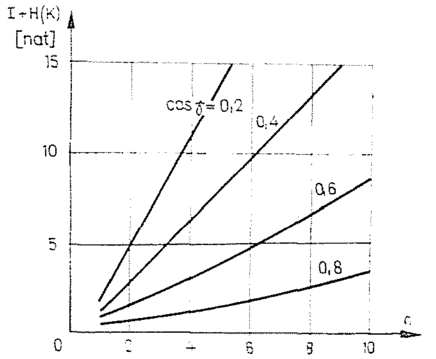

Fig. 11. Transinformation limited by uncertainty trajectory

Let us rewrite the second relation in the following form:

$$\ln\left|\frac{v - v_n}{v}\right| = \sum_{i=1}^{2n} \ln|\cos\gamma + \xi_i \sin\gamma|\,,$$

wherefrom the distribution of the random variable

$$\eta = \left|\frac{v - v_n}{v}\right| = \left|\prod_{i=1}^{2n} (\cos\gamma + \xi_i \sin\gamma)\right|$$

is clearly seen to approximate the logarithmic normal distribution.

Now let us introduce expressions

$$\begin{aligned} M[\ln|\cos\gamma + \xi\sin\gamma|] &= m_0\,, \\ D^2[\ln|\cos\gamma + \xi\sin\gamma|] &= \sigma_0^2 \end{aligned} \tag{23}$$

whence the frequency distribution of η will converge to the frequency distribution

$$f(y) = \frac{1}{\sqrt{2\pi}\sqrt{2n}\,\sigma_0\, y} \exp\left(-\frac{(\ln y - 2nm_0)^2}{2\cdot 2n\sigma_0^2}\right) \tag{24}$$

and the entropy of η will read

$$H(y) \approx \ln \sqrt{2\pi e}\sqrt{2n}\,\sigma_0 + 2nm_0 . \tag{25}$$

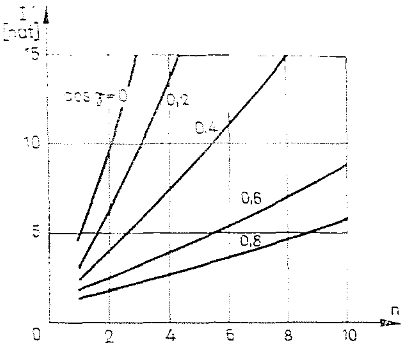

Fig. 12. Transinformation limited by uncertainty indication

At the same time, substituting η into Eq. (22):

$$v_n = v - v\eta$$

wherefrom, at a fixed v, the conditional entropy will be

$$H(V_n|v) = H(y) + \int f(y)\ln|v|\,dy = H(y) + \ln|v|$$

whereas the mean conditional entropy:

$$H(V_n|V) = H(y) + \ln v_m - 1 .$$

Let us again substitute $H(V_n)$ by $\ln v_m$, whereby we get the transinformation sought for:

$$I(V, V_n) = H(V_n) - H(V_n|V) \approx 1 - \ln\sqrt{2\pi e}\sqrt{2n}\,\sigma_0 - 2nm_0 . \tag{26}$$

Fig. 12 illustrates the formation of the transinformation as a function of n. The parameter of the curve set is $\cos\gamma$, and as the distribution of ξ reflecting the uncertainty of indication, a uniform distribution has been assumed in the ± 0.2 region, to represent a suitable practical value.

Two different uncertainty sources limiting transinformation have been studied above. Figs 11 and 12 revealed results of similar trends. In a given case the two instability sources have exerted simultaneous action and, there, the formation of I—n is described by a resultant curve below the two component curves, with a character similar to that in Fig. 13 *a*. Now let us analyze the redundance of different compensation methods on the basis of this resultant curve.

Let us assume that, according to the measurement specifications, a H_0 quantity information must be obtained on v. Fig. 13 *a* reveals that at least

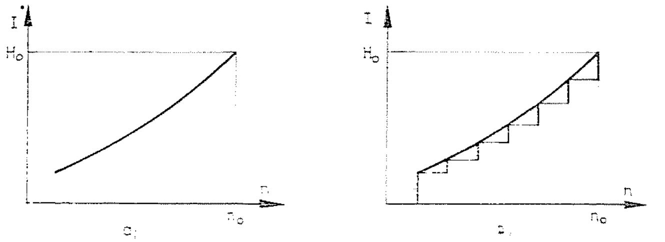

Fig. 13. a) Maximum information content of measurement; b) Information diagram of compensation without redundance

n_0 iteration steps are required for this purpose. If, in the compensation process, the previous information is fully used in each step, and all further transinformation is acquired without redundance, the compensation process will be free of redundance. The information diagram characteristic of this case is presented in Fig. 13 *b* where the full lines indicate information "invested" in each step. The practical realization of this diagram is, however, impossible and even its approximation is extremely complicated and expensive. Let us study, therefore, the redundance of the practically adaptable compensation methods.

a) Compensation is done in each iteration step at maximum precision, by starting all over again. The information diagram is presented in Fig. 14 *a*. The relative information excess (which is, at present, much more illustrative than the redundance) of this process, that is, the ratio of invested to acquired information, amounts to $\dfrac{n_0 H_0}{H_0} = n_0$.

b) Compensation is done from the very beginning in each iteration step, but only up to the precision reasonable in that step. If the curve I—n can properly be substituted by a straight line passing the origo (see Fig. 14 *b*), then the relative information excess of the process is $\dfrac{n_0 + 1}{2}$.

c) The acquisition of much less information than permissible is aimed at in each step. This actually means that compensation is done by a much greater quantity than permitted. In such cases a greater part of the information previously obtained may be made use of subsequently. The information diagram characteristic of this process is presented in Fig. 14 *c*. Although this figure displays no redundance, in reality also this method has some, because each compensation step must provide for a possibility to return to the previous quantums, that is, the stages reflecting invested information should over-

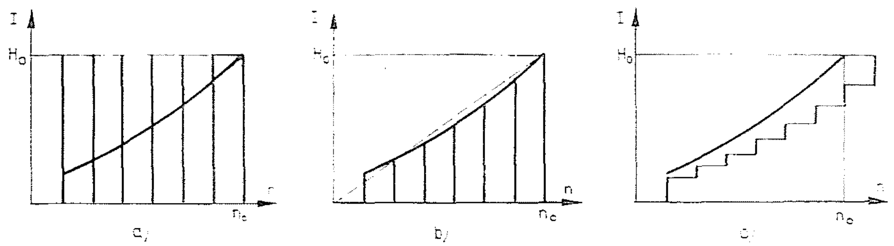

Fig. 14. Several information diagrams

lap. As shown by a more detailed analysis, the redundance will increase with an increased n_0, still much less, however, than for cases *a)* or *b)*.

d) The method *c)* is separately considered at a 90° angle of convergence ($\cos \gamma = 0$). This is where the number of the iteration steps required is the lowest, just like the redundance of overlapping as described above. In certain cases the square net trajectory corresponding to the $\cos \gamma = 0$ condition is *a priori* given (for example an alternating voltage complex potentiometer). In other cases the $\cos \gamma = 0$ condition can be achieved either in digital or in analogue way. These trajectory linearization techniques essentially retransform the distored trajectory of the error voltage in square net through calculation. The redundance of the compensation methods in this category is far the lowest among all the practically adaptable methods.

5. Conclusion

On the basis of the previous chapters, the total time needed by measurement can be written. If in one iteration step the indicator channel has to transfer I_0^* quantity of information, this step has a proportional time requirement according to curve *d* in Fig. 9.

Let this time be $k \cdot I_0^*$. The integrating measurement of sinusoidal signal and the intervention into the network have also their time needs (t_m and t_i resp.). Thus the time of one iteration step is

$$kI_0^* + t_m + t_i \, .$$

Let us mark the total information of measurement by I, and the trans-information of one step by I_0. The total measuring time will be the time of one iteration step multiplied by the number of iteration steps (I/I_0):

$$T = \frac{I}{I_0}(kI_0^* + t_m + t_i) \, . \tag{27}$$

The measuring time (t_m) and the intervention time (t_i) are generally given just as the total information of measurement (that is the needed accuracy of measurement) marked by I.

Now, the total measuring time can be reduced by

decreasing k. It will decrease by using a filter with smaller transient time,

decreasing the I_0^*/I_0 redundance,

decreasing the number of iteration steps, possible by increasing the quantity of I_0 that is the transinformation of one step.

On the basis of results of these examinations, a digital compensating system is being developed at the Department of Instrumentation and Measurement of Budapest Technical University.

The measurements have proved it possible to measure both components of sinusoidal signal with 4 bits of transinformation. The time needed for measuring is a double quarter period — that is a half period. Measuring with 4 bits permits tenfold improvement of compensation in each iteration step.

We have finished the simulation tests of the complete instrument on a digital computer. On the basis of results, applying a system to 50 c/s, the maximum rate of information transmission will be 80—100 bits/sec.

Summary

The rate of high precision A.C. measurements — for example by A.C. bridges — can be increased. Using the methods of information theory, factors slowing the measurements proper to measuring network, indicator and compensation algorithm are exhibited. A new method based on results of these examinations is described for high-speed digital compensation of A.C. networks.

References

1. REZA, F. M.: An introduction to information theory. McGraw-Hill. 1961.
2. BELL. D. A.: Information theory and its engineering application. Pittman Publ. Co. New York. 1962.
3. NOVITSKI, P. V.: Poniatie entropinovo snatshenia progresnoshti. Izmeritelnaia tehnika. 1966. 7.
4. NOVITSKI, P. V., IVANOVA, V. JA., KONDRASHOVA, G. A.: Izmeritelnaja Tehnika, 11, (1966).
5. WOSCHNI, E. G.: Application of information and system theory in the measuring technique. Messen, Steuern, Regeln **10**, 12 (1967).
6. WHITE, W. E.: The optimal conditions of convergence in alternating-current bridge networks using phase-selective indicators. IRE Trans. Instrumentation, **I—6**, Sept. (1957).
7. KNELLER, V. Y.: A. C. bridges with balancing in two parameters. Automation Remote Control **19**, Febr. (1958).
8. SELÉNYI, E.: Balancing properties of current comparator capacity measuring network. Periodica Polytechnica El. **13**, (1969).
9. STERNES, K. J., LOONEY, J. C.: Impedance bridge balancing using perturbation theory. IEEE Trans. on Instrumentation and Measurement **IM—18**. June (1969).
10. TURKIYA, G., FOORD, T. R., LANGLANDS, R. C.: Logic circuits for a continuously self-balancing transformer-ratio A. C. bridge. Control, Oct. (1967).
11. Methods of measuring impedance. Hewlett-Packard Journal 1967/1.
12. Autobalance universal bridge B—641. Wayne-Kerr Technical Information.
13. Type 1680—A Automatic capacitance bridge assembly. The General Radio Experimenter 1964/8.
14. LEONG, R.: The automatic impedance comparator. The General Radio Experimenter 1968/6—7.

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