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INSTRUMENT TRANSFORMERS IN VIRTUAL INSTRUMENTS

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Abstract: The use of instrument transformers in virtual electronic instruments poses certain problems. This paper points to some of these problems and the possible ways of dealing with them. Specific examples dealing with improvements made to the standard-type inductive measurement transformers, as well as some unconventional models of instrument transformers are presented.
Keywords: instrument transformer, virtual instruments , unconventional transformer

1 INTRODUCTION

The development of electric measurement instruments has passed through various technological and technical phases. The current phase bears the designation "virtual instruments" and is characterised by relatively standard hardware supported by PC and software based on object programming. The function and structure of electric instruments, however, have not changed much. The basic function of measurement instruments, no matter whether they are analog, digital or state-of-the-art virtual instruments, is transformation of the characteristic being measured into numerical terms. In principle, measurement instruments have a standard structure, shown in Figure 1, consisting of three basic elements: the section serving to adjust the input characteristic being measured, the section serving to process and transform it into scalar (numerical) terms, and the section serving for visual presentation of measurement results.

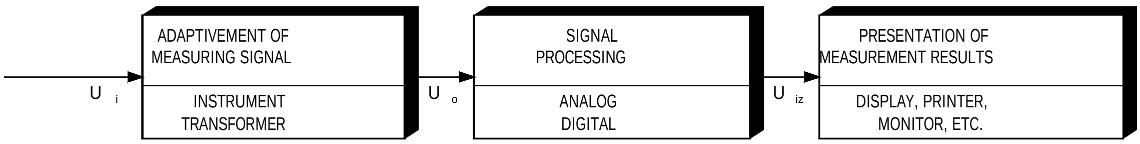


Figure 1. A structural model of measurement instruments

The adjustment section usually separates the measurement circuit from the energy, control, regulation or other electric circuits. In alternating current circuits it is usually effected by means of instrument transformers. Instrument transformers have been in use for over one hundred years. In the course of this relatively long period of time (from the point of view of technology), marked improvement has been achieved in the design and manufacture of instrument transformers. The standardisation of metrological-technical characteristics, which was effected relatively early on in the process, significantly contributed to that. The standard values of nominal secondary currents, voltage and load were adjusted to the requirements of the analog instruments and induction meters that had been used before.

The nominal secondary voltages of $100/\sqrt{3}$ and 100 V, as well as nominal secondary currents of 1A and 5A, are not adequate for direct application in the electronic circuits, where voltage is usually of the order of magnitude of 1 V and current of 1 mA. A change in the nominal values of the secondary voltage and current entails a number of problems in the manufacture of these instrument transformers and their testing for accuracy. The solutions to these problems have been sought following two divergent lines of development: radically different (unconventional) instrument transformers with corresponding secondary characteristics values, and additional instrument transformers adjusting the voltage and current to the desired optimum levels. The future certainly belongs to the former, but the practice so far favours the latter. The paper presents some characteristic instrument transformer designs from both these groups.

2 INDUCTIVE INSTRUMENT TRANSFORMERS

Direct transformation of a 100 A primary current into a mA current would pose a technological problem, if only due to the fact that the secondary winding should have over 100,000 turns, which is a serious technological problem in the torus variant of the magnetic circuit. By using two instrument transformers, for example: 100A/1A and 1A/10 mA, the number of secondary turns is reduced by at least one hundred times, which considerably facilitates the realisation of such transformers. The additional instrument transformer, however, presupposes additional measurement error. It is, therefore, of utmost importance that the phase and amplitude errors of such additional transformers should be as small as possible.

Instrument transformer errors are determined by design-technological and exploitation parameters. Among the former, the magnetising current and the impedance of the primary and secondary windings influence the magnitude of the error the most; among the latter, the magnitude and type of secondary load. Ideally, they should all be negligibly small. In practice, there are limits to the possibility of achieving this ideal model of instrument transformer, and the actual models realised are of the accuracy class of up to 0.02. Further reduction of the error magnitude is achieved through non-standard designs. In practice, the most frequent ones involve electronic compensation of instrument transformer error [1].

By applying electronic compensation, it is possible to reduce instrument transformer error by up to two orders of magnitude. These solutions are, as a rule, characterised by complex hardware structure, and problems to do with the stability of functioning occur. That is why speculations on software error correction make sense.

Metrologically speaking, inductive instrument transformers are very stable and dependable elements. The accuracy of instrument transformers basically depends on the construction and exploitation parameters. The key construction parameters are: the magnetic circuit, the number of windings in the primary and secondary coils; they are unchanging in terms of time and temperature. In virtual instruments, instrument transformers are under very favourable and stable working conditions.

An example of a current transformer, 25A/5A, may show the purpose of software error correction. This current transformer was systematically tested for accuracy over a period of three months. The results of amplitude and phase error testing were classified as the mean values of 50 individual measurements, and are presented in Table 1. In addition to the mean values of amplitude and phase errors, the corresponding standard deviations are given as an indicator of the reproducibility of the measurement itself, and also of the metrological stability of error of the transformer being tested.

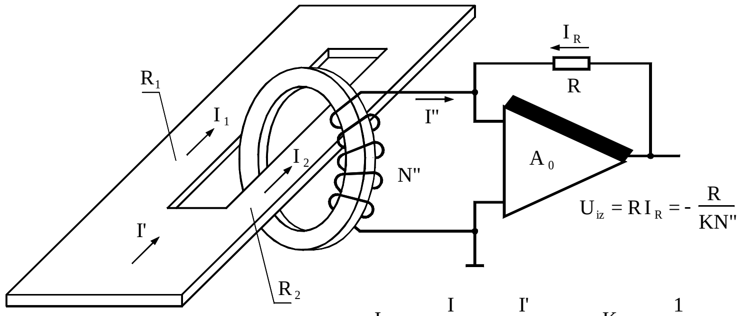
Table 1. The results of accuracy testing current transformer

I''/I''_N(%)	S(VA)	g_{sr}(%)	s_g(%)	d [′]	s_d [′]
5	10	-0.574	0.0112	25.91	1.17
20	10	-0.236	0.0045	13.41	0.36
100	10	-0.024	0.0027	5.67	0.23
120	10	-0.068	0.0032	6.78	0.21

It can be seen that the systematic mistakes of the transformer being tested are greater than the corresponding standard deviations, that is, the values of randomly changing current transformer error, by one order of magnitude. This makes possible software correction of the systematic errors of the transformer being tested, particularly in the case of PC-based virtual instruments. The category and type of software error correction may be discussed at length, but it is certainly no great problem, either mathematically speaking or from the point of view of programming, irrespective of the fact that we are not dealing with linear error correction here.

By applying software error correction only, the accuracy of the current transformer being tested may be significantly improved, so that instead of the initial accuracy class of 0.5, we get an instrument transformer of the accuracy class of 0.1. This method of accuracy enhancement was more characteristic of some other measurement instruments, although, taking into consideration the nature of the problem, it is entirely appropriate for instrument transformers. The solution of another current problem pertaining to instrument transformers for electronic meters justifies this line of reasoning. Namely, in accordance with international standards for electronic meters, current instrument transformer error is tested for certain values of direct current. Current transformers with a magnetic circuit made of high-quality soft magnetic material do not meet this additional requirement. The solution was found going the other way round, using materials of lesser magnetic permeability (of Permax type), which react much better to the presence of direct current. The amplitude error of such current transformers reaches up to several per cent, and the angular error up to several degrees. However, as these errors are constant, a relatively simple and efficient software error correction is possible, so that the actual error is brought down to an acceptable level.

One of the technological problems in the manufacture of inductive current transformers for primary currents of 100 A and more is the great number of windings of the secondary coil (ten thousand and more). This problem may be resolved by dividing the primary current, by means of a shunt, by, for example, a 1:10 ratio, so that only a small portion of the primary current gets transformed into secondary current by means of current transformers. Figure 2. shows the whole process of primari current transformation.



$$I_2 = \frac{I}{1 + \frac{R_2}{R_1}} = \frac{I'}{K} \qquad K = \frac{1}{1 + \frac{R_2}{R_1}}$$

$$n = \frac{N''}{N'} \quad \Rightarrow \quad n = N''$$

$$N' = 1$$

Figure 2. Basic split-conductor current transformer

The construction of the shunt may vary, depending on the technology applied. It is essential that the dimensions of the shunt correspond to the full nominal value of primary current. By means of these so-called split transformers, it is possible to transform primary current ranging from 1 A to 300 A into corresponding secondary current or voltage, whose error level does not exceed 1% or 60' [2].

Testing instrument transformers for accuracy poses another problem because the standard measuring equipment is designed for conventional instrument transformers. The Electrical Engineering Institute “Nikola Tesla” has developed methods suitable for testing the accuracy of instrument transformers with non-standard transformation ratio [3]. These measurement methods are based on a two-channel network analyser which can measure very precisely two successive voltages and their phase . The accuracy of measurements performed using this device, however, is below the level of accuracy achieved using the measurement equipment designed for testing the accuracy of standard instrument transformers. It may reasonably be expected that these additional instrument transformers will be standardised in the future.

This would certainly facilitate the manufacture and testing these instrument transformers for accuracy, and would also affect production costs. Even now, several manufacturers offer current instrument transformers suitable for this particular use. These are torus transformers with a secondary winding consisting of 1,000 and 2,000 turns. The dimensions of these transformers have been minimised to the utmost, and their shape and electrical connections have been adapted for printed cards. The error margin of these current transformers available on the market at the moment is of the order of magnitude of 0.2% and 30 min. in the 5-120% nominal current range. The price per unit is less than DEM 10, that is, considerably lower than in the case of manufacturing single units.

The secondary load of these transformers is very much reduced, due, first of all, to the reduction of the secondary current. In the case of secondary voltage of the order of magnitude of 1 V it is of the order of mVA. There also remains the possibility of closing the secondary winding of the transformer practically with zero impedance, as in the connection of the current-voltage transformer to the so-called virtual mass shown in figure 3.

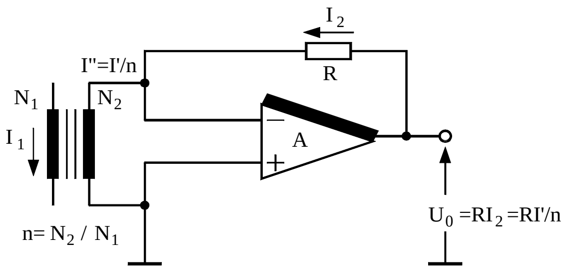


Figure 3. Current instrument transformer as a current-voltage transformer connection

With this type of design the instrument transformer error depends only on the impedance of the secondary winding and the magnetising current, which can be lowered to the desired level by means of construction and technological parameters. Concerning their construction and measurement parameters, these additional instrument transformers are thoroughly compatible with standard electronic circuits for measurement, protection and regulation. In electronic component catalogues they are designated as PCB mounting transformers.

The need for additional instrument transformers will probably remain for quite a long time, due, if nothing else, to the fact that power circuits are separate from the measurement circuits, that is to say, that it is not possible to introduce directly high voltage of the order of magnitude of kV or current of the order of magnitude of kA into the electronic circuits. That is why in power-generating equipment instrument transformers are placed separately from the measurement instruments. The transmission of low-level current and voltage signals (mA and V) would be less favourable from the point of view of the signal-noise ratio as well, that is, the influence of electromagnetic disturbances in relation to the existing standard level (1 A and 5 A, and 100 V)

In the case of low-voltage measurements, such as the measurement of power consumption in individual households, the use of two current instrument transformers would not be a convenient solution. In the case of contemporary electronic meters, the classical-type inductive current transformers take up three quarters of the space available inside the housing of the meter and make for almost half the total cost of the meter. Due to both these reasons, the solutions to this are being sought in the form of essentially different instrument transformers.

The development of industrial electronics has created two new metrological problems. The first of them is the measurement of very deformed alternating currents and voltages in an extended frequency range, whereas the second one is the measurement of alternating voltages and currents accompanied by a significant direct current. With classical inductive current transformers it is possible to solve the first problem but not the second. Here, too, the solution lies in radically different unconventional instrument transformers.

3 UNCONVENTIONAL INSTRUMENT TRANSFORMERS

The term “unconventional instrument transformers” in professional publications is used to designate optical instrument transformers, although it may be used, in a more general sense, to refer to all the other types of design that deviate from the standard-type inductive transformers. The number of these alternative designs is so large that they cannot all be dealt with within the scope of this paper.

Current transformers based on interinductivity in the astatic connection, developed by the experts at PTB (Phisikalishe Technishes Bundesanstalt), is one such unconventional design. Figure 4a. shows the physical make-up of this type o current transformer, while Figur4b. shows its electrical scheme [4].

The current transformer consists of a common primary winding, copper plates with corresponding air holes. Two identical secondary windings in astatic connection are placed in these holes. This means that the influence of outside electromagnetic field, which is identical for both windings, gets cancelled for the most part owing to the astatic connection, so that these solutions do not require electromagnetic shilding.

The electromotive force E corresponds to the measured current I_1 in the primary winding in accordance with the equation:

$$E = j w MI¢ \qquad (1)$$

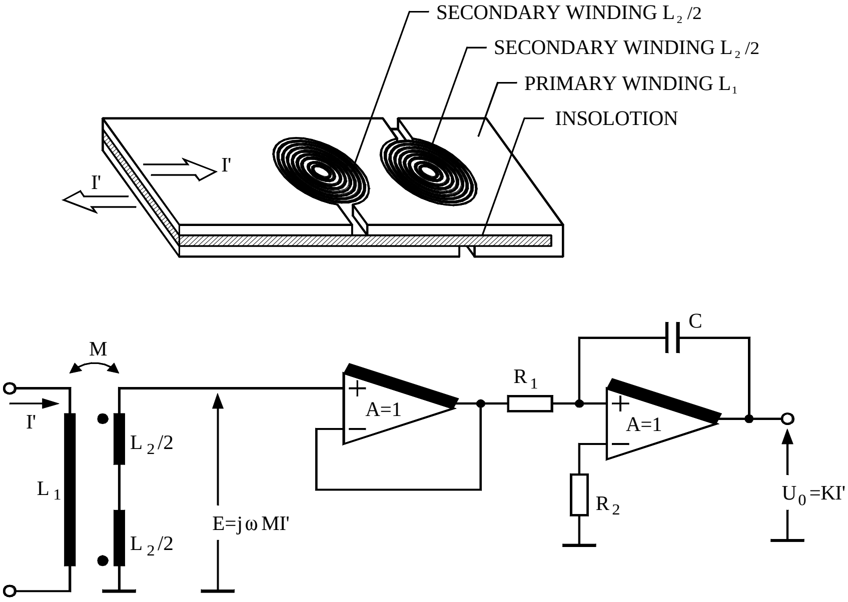


Figure 4. Current transformer based on interinductivity in astatic connection

As it is dependent on frequency, the measurement of non-sinusoid currents would result in non-linear transmission and additional measurement errors. This problem, as well as the phase shift of the electromotive force to the extent of $\pi/2$ in relation to the current measured in the primary winding, is resolved by means of corresponding electronic circuits, namely – emitter-follower and integrator. The output voltage of the integrator exhibits a linear dependence on the current measured and is in phase with it. The accuracy of transformation achieved by means of this current transformer falls within the range of amplitude error of 0.5% and phase error of 20′.

The Swiss company LEM has developed a current transformer (LTS25-NP) for PCB mounting [5]. This type of transformer functions based on the well-known principle of inductive direct-current transformer where the magnetic flux in the core is controlled by means of a Hall sensor and the secondary current is generated by means of an operative amplifier in negative feedback; in the secondary winding, this current generates a magnetic flux of the same intensity as the magnetic flux of the primary winding but of the opposite sign. In this way, both direct and alternating primary currents may be transformed. Fig. 5 shows a block diagram of this type of current transformer.

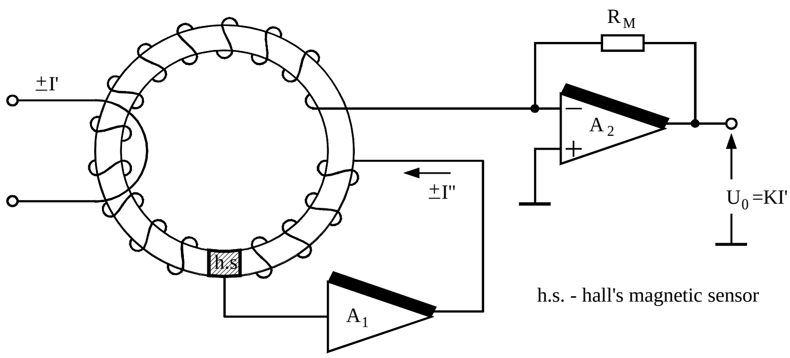


Figure 5. Block diagram of type LTS25-NP current transformer

The primary nominal current of ± 25 A is transformed into secondary current of 12.5 mA, and the corresponding voltage is transformed accordingly by means of an output amplifier. Two options are possible: with + 5 V and ± 15 V power supply. Using this type of current transformer, it is possible to measure primary currents in the frequency range from DC to 100 kHz, in which case the transformation error does not exceed 0.25 dB, or in the frequency range of up to 200 kHz, in which case the error does not exceed 1 dB. The linearity of this transformer is better than 0.1% in the primary current range of 1% I_N to 100% I_N. The functioning of the transformer is limited for input currents of up to 3 x I_N, which in this particular case means that it is possible to measure currents of up to 80 A over a short period if time. The transformation speed of 6 kV/µs makes this transformer suitable for use in protection and regulation circuits. The working temperature ranges from -10^{o}C to 50^{o}C. Within this temperature range the output drift does not exceed 50 ppm/^{o}C, so that the overall current error of this type of transformer does not exceed 0.2% and the phase error does not exceed 30 min. The isolation level is defined at 500 V. Although they are good, these metrological-technical characteristics are not worthy of particular interest.

The quality and innovativeness of this design is of technological nature because the whole transformer is produced in the single ASIC technology. It is diminutive as far as size is concerned (dimensions: 9.3 mm x 2.2 mm x 24 mm), and does not occupy more than 2 cm^2 on a printed plate. Owing to the manner of its manufacture, it may reasonably be expected that its price will be minimal, which would pave the way for more widespread use of these transformers.

4 CONCLUSION

Instrument transformers, being indispensable elements of measurement, regulation and protection circuits, at the same time connect and separate power and electronic circuits. This somewhat paradoxical requirement indicates that problems may occur, and in reality they indeed do. This paper points to certain problems pertaining to the manufacture and testing of instrument transformers. The paper presents some new designs, both in the sphere of improving standard-type inductive transformers and in the sphere of unconventional instrument transformers. The purpose of this paper is to encourage research into this significant and interesting problem area.

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