PERFORMANCE OF THE C-CORE PARAMETRIC TRANSFORMER

F.E. ABDEL-KADER*, A.S. ABDEL-KARIM*,
S.A. HASSAN**, S.A. KALILAH***

ABSTRACT

The C-core parametric transformer is unusual in its construction and features. It can be used as a single-to-two phase converter, frequency multiplier and voltage stabilizer.

In this paper an equivalent circuit representing the device at the fundamental frequency is proposed. Effects of saturation, core losses, winding resistances and leakage reactances are taken into consideration. In order to examine the validity of the proposed equivalent circuit an experimental model is built and tested. Performance characteristics of the device are calculated and compared with the test results. It is shown that, due to the proposed equivalent circuit calculations are greatly simplified and satisfactory results are obtained.

* Associate Professor, ** Professor, *** Gradute student,

Department of Electrical Engineering, Faculty of Engineering and Technology, Menoufia University, Shebien El-Kom, Egypt.

INTRODUCTION

Due to its unusual construction and unique features [1-3], the C-core parametric transformer has, sometimes, been classified as a power converter [4,5]. It is being produced by Wanlass Electric Company For use in the United States military equipment. This is due to its possible applications as single-to-two phase converter, frequency multiplier and voltage stabilizer.

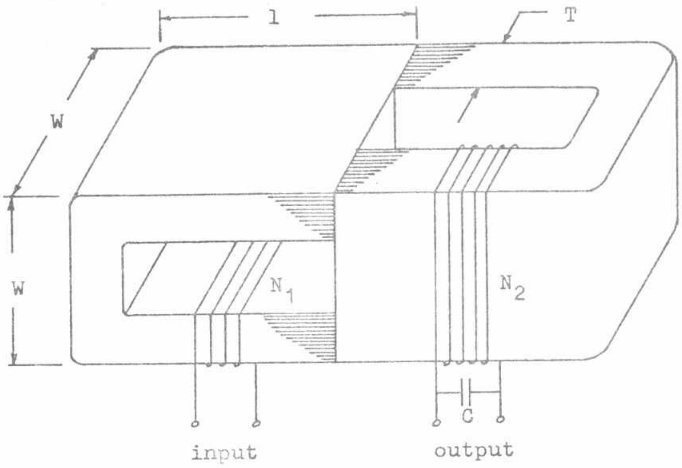

Fig.1. The C-core parametric transformer

Fig.1 shows the core and coils arrangement of the device; the two core-portions are identical and being placed such that they are 90^o relative to each other in space.

Based on so called parametric coupling a theory of operation for the device has been developed [1]. Recently, this theory has been critically discussed and shown to be inconsistent [3]. In reference [3] it has been established that the device operation is based on the phenomenon of ferroresonance. Also, the ability of the secondary coil to resonate is due to an initial flux in the secondary core. This flux coupling may be enhanced by the effect of the tuning capacitor. It has been concluded that, in normal operation the two device coils are magnetically coupled, but such a coupling condition can only be maintained by the presence of the tuning capacitor.

Alternative structures which could give similar performance have been developed [2,5,6]. Those have shown that orthogonality of fluxes in primary and secondary cores is not a must for achieving a similar behaviour. Neverthless, the C-core structure appears to be unique as a frequency multiplier, since its filtering action produces nearly pure sinusoidal output [1,2].

Analysis of the device has been the subject of a number of papers [5-9]. Mathematical formulation in the form of nonlinear differential equations for primary and secondary circuits has been used and solutions based on simplifying assumptions have been developed. Such an approach is tedious and requires exhaustive work for parameters identification. Numarical solution using a state model has also been performed [9], but results have not been verified by experiment.

In this paper an equivalent circuit model for the device is proposed. Steady state performance is computed taking into account the effect of saturation and core losses. However, dynamic inductances and effective values of the circuit variables are used. Validity of the proposed equivalent circuit is verified by comparing calculated and experimental results of a test model.

SOME PRELIMINARY OBSERVATIONS

Referring to Fig.1, if the capacitor is removed and the primary coil is excited such that common regionsof the core are saturated, very small distorted voltage appears across the secondary coil. If a capacitor of a suitable value is then used, a "jump" in the coupling level between the two transformer coils can be achieved. Accordingly, the secondary voltage "jumps" to the normal value, and the secondary core portion becomes heavily saturated. However, if the capacitor is initially connected and the primary voltage is gradually increased, a similar action is obtained. Also, if the device is loaded, the action will be similar provided that the secondary circuit is underdamped. Results of the above test are shown in Fig.2, with and without the capacitor on the secondary of the test model.

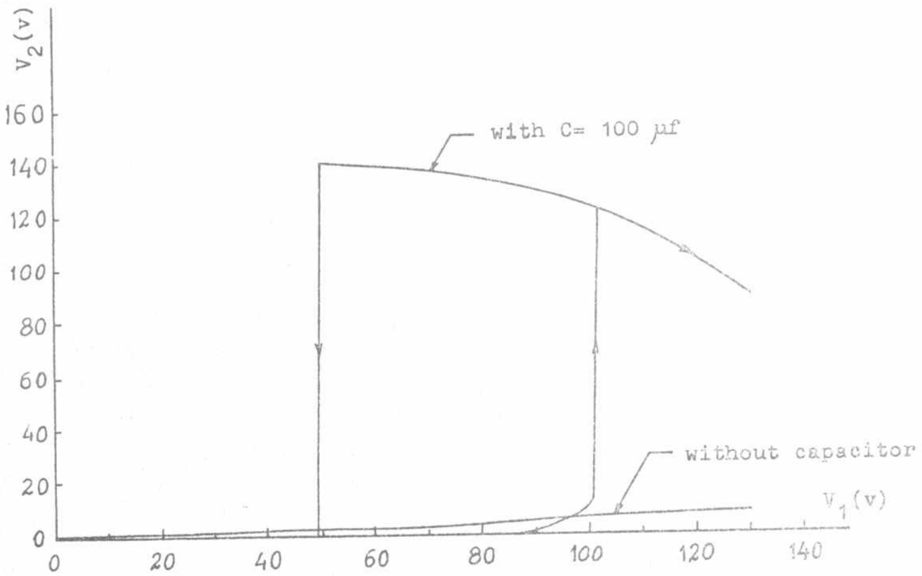

Fig.2. Variation of V_2 with V_1 for unloaded secondary

It may be worth mentioning that the starting operation of the device when used as a frequency multiplier is similar to the above, but lower capacitor values are required.

Test results have also shown that level of the output voltage is affected by the capacitor value, e.g. by the saturation level. If the capacitance is fixed, output voltage will be slightly affected by the variation in the load resistance. However, reduction in the load resistance reduces the effective capacitance and so large reduction may result in complete collapse of the output voltage. Further details about the device behaviour could be found elsewhere [1,2].

THE PROPOSED EQUIVALENT CIRCUIT

In order to devise a suitable equivalent circuit for this device the observed behaviour of it together with the following points have been considered.

a) Flux levels of primary and secondary core-portions are nearly determined by input and output voltages, respectively. Thus, some leakage fluxes are present.
b) The difference between primary and secondary flux components circulates through the common regions of the core. Such a leakage flux can be attributed to the condition of forced coupling for the device coils.

Based on the observations and points (a) and (b) above, a π-like equivalent circuit for the device can be set up as shown in Fig.3. This circuit is used for the device operation when secondary circuit resonates at the supply frequency.

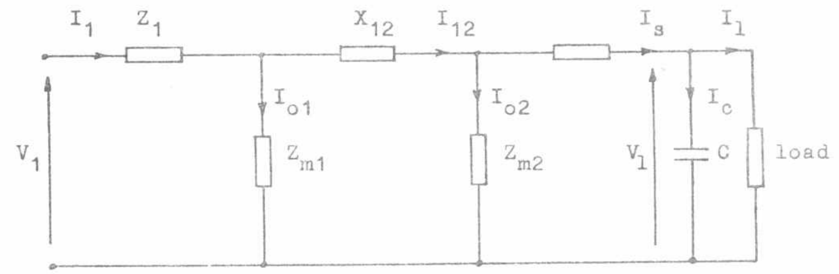

Fig.3. The proposed equivalent circuit

Parameters of the proposed equivalent circuit are referred to the device structure as follows. Z_1 and Z_2 represent resistances and leakage reactances of primary and secondary coils. Since most of the leakage flux is in air, the concept of linear leakage reactances can be applied. Z_{m1} and Z_{m2} represent primary and secondary core-portions, respectively. The effect of saturation can be taken into account by considering the dynamic reactance values according to the operating flux level. However, each core-portion losses can be fairly represented by a linear resistance paralleled to the corresponding magnetising reactance [4]. The parameter X_{12} is a reactance which represent the primary-to-secondary leakage fkux. Due to the unusual structure of the device, procedures devised for measuring the equivalent circuit parameters are summarized subsequently.

PARAMETER MEASUREMENTS

For this purpose an auxiliary coil mounted with each of the primary and secondary coils was used. Also, during the parameter measurements the tuning capacitor and load resistance were removed. In the test model, primary and secondary are of equal number of turns. However, if this is not the case, the measured parameters may be referred to either side in the conventional way.

In order to measure the primary or secondary leakage reactance, the auxiliary coil was short circuited and the conventional short-circuit test was then performed. Due to symmetry, leakage reactances on both sides were found equal.

Z_{m1} and Z_{m2} were measured as follows. The two core-portions were alined so that a common path for primary and secondary fluxes was formed, i.e. the 90^{o} displacement was eliminated. The two main coils were connected in series to a variable voltage a.c. source. The conventional open-circuit test was then performed such that the possible range of flux variation was covered. A mean value for each core-portion loss resistance, R_m , was calculated. Variation of the magnetising reactance, X_m, was plotted as shown in Fig.4; at the same flux level $X_{m1} = X_{m2}$ since the two device sides are identical.

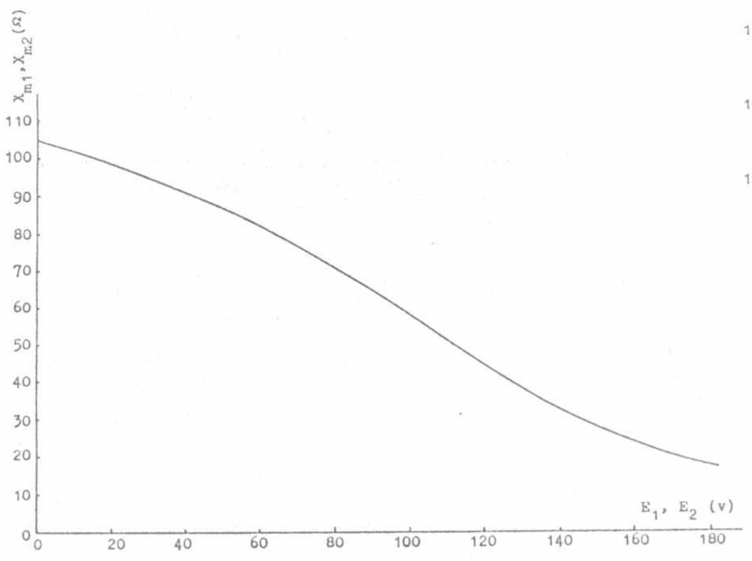

Fig.4. Variation of magnetising reactance with induced voltage (at 50 Hz)

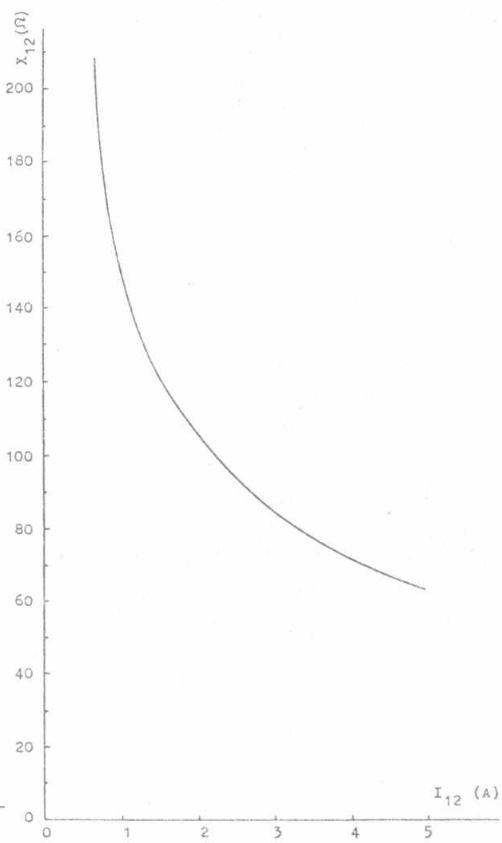

Fig.5. Variation of X_{12} with I_{12} (at 50 Hz)

In order to measure the reactance X_{12}, consider the proposed equivalent circuit shown in Fig.3. If the secondary is short-circuited and a variable voltage is applied at the primary coil, then using the readings of the input voltage, primary and secondary currents together with the equivalent parameters measured above, variation of X_{12} with I_{12} can be obtained. The measured variation of X_{12} is plotted as shown in Fig.5.

In order to achieve accurate results, e.m.fs. rather than voltages should be used for determination of the magnetising impedances and X_{12} . Primary and secondary e.m.fs. can be measured via the auxiliary coils. Design data of the experimental model are given in the appendix; values of the constant equivalent circuit parameters are also listed there.

VERIFICATION OF THE PROPOSED EQUIVALENT CIRCUIT

Because of the flux dependent parameters, a general solution for the equivalent circuit can not satisfy different operating conditions. The operating points of X_{m1} , X_{12} and X_{m2} are determined by the variables E_1, I_{12} and E_2, respectively. Thus, iteration steps may be carried out to approach a solution for every operating condition. For instance, if certain capacitance and load resistance are considered, then defining V_1 initial values for E_1 and E_2 can be assumed; X_{m1} and X_{m2} are accordingly determined from Fig.4. Using the equivalent circuit and E_2 above, I_{12} can be calculated and so the corresponding X_{12} can be read from Fig.5. The initial values of X_{m1}, X_{m2} and X_{12} can then be used to obtain new values for the circuit variables E_1, E_2 and I_{12}. According to those new values, X_{m1}, X_{m2} and X_{12} are renewed using Figs.4&5. Those are taken as initial values for another iteration step and the operation is repeated until a reasonable conversion is achieved.

Considering the above procedure, solution of the equivalent circuit for every iteration step is elementary and need not be reported. A solution for the device performance was carried out using the circuit parameters of the last iteration step. However, a simple computer programme , in which the curves defining X_{m1} , X_{m2} and X_{12} were numerically stored, was written and the device performance was computed. Figs.6&7 show the computed and experimental results for the conditions V_1 = 110 volts, C = 100 µf and different values of load resistance. It is obvious that computed and test results are in good agreement.

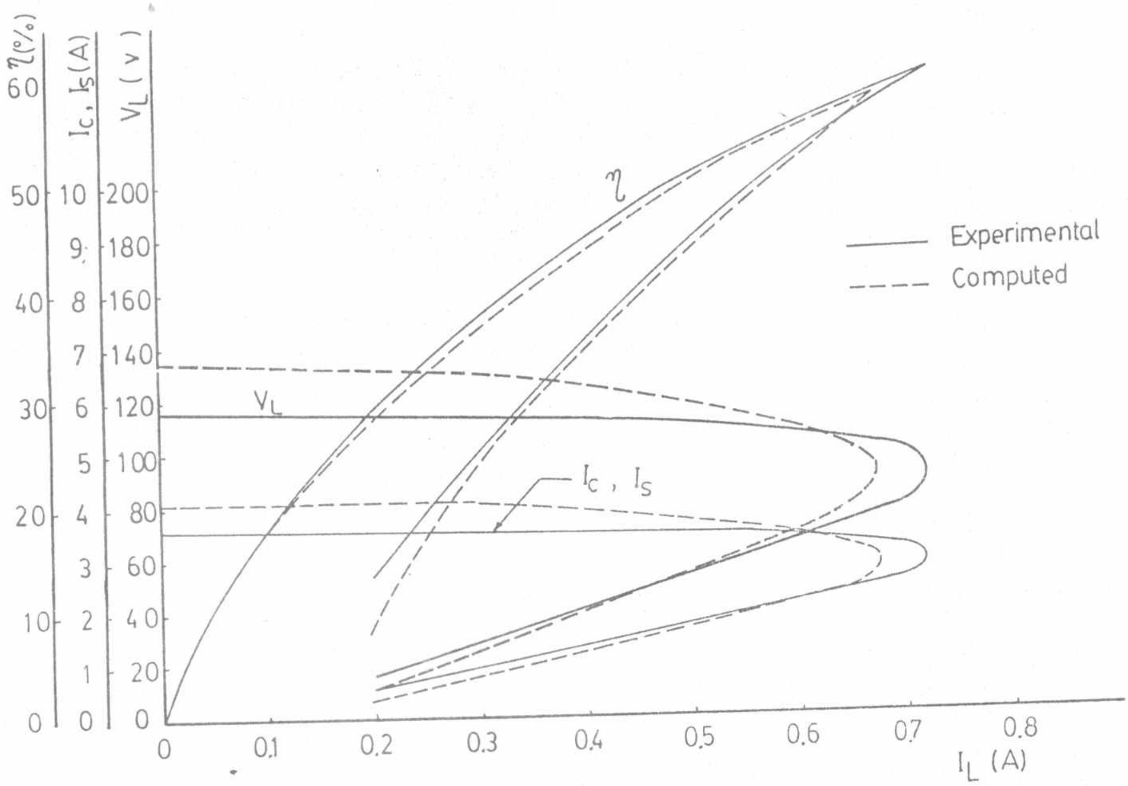

Fig.6. Variation of V_L, η, I_C & I_S with load current at C = 100 μf, V_1 = 110 v

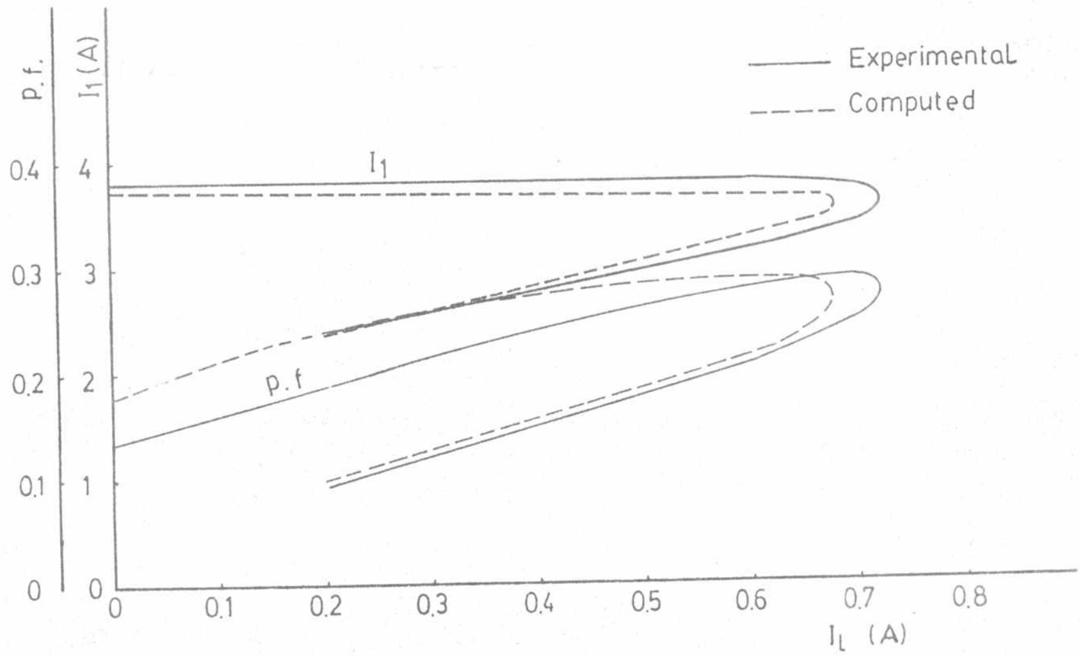

Fig.7. Variation of I_1 & p.f. with load current at C = 100 μf, V_1 = 110 v

CONCLUSIONS

Performance of the C-core parametric transformer can be predicted using the approach of equivalent circuits. The solution is greatly simplified and the labour required for performance computation is minimal. Using an iterative solution, the nonlinearities have been fairly considered. The computed and experimental results have been shown to agree satisfactorily.

Parameters of the proposed equivalent circuit are measurable using the tests devised for this purpose. The proposed arrangement for the equivalent circuit parameters can be applied to other alternative structures of the device.

REFERENCES

1. Wanlass et al, S.D., "The Paraformer", IEEE Wescon. Tech. papers, Part 2, Vol. 12, 1968.
2. Kalilah, S.A., "The Parametric Transformers", M.Sc. Thesis, Menoufia University, 1983.
3. Abdel-Karim, A.S.,Abdel-Kader,F.E.,Kalilah,S.A., "Theory of Operation of the Parametric Transformer", Eng. Res. Bul., Faculty of Eng. & Tech., Menoufia Univ., Vol. V, Part 2, 1983, pp. 121-132.
4. Burian,K., "Theory and Analysis of a Parametrically Excited Passive Power Converter", IEEE Trans. Industry Applications, Vol. IA-8, No. 3, 1972, pp. 278-282.
5. Bessho, K.,Matsumura,F.,Susuki,M., "Some Experiments and Considerations on Behaviour of the Power Converter with Bridge Connected Reactor Circuit", IEEE Trans. Magnetics, Vol. Mag-10, No. 3, 1974, pp.965-68.
6. Fam, W.Z., Bahl, G.K., "Two Related Types of Parametric Transformers", ibid, No.3, 1974, pp. 690-693.
7. Fam, W.Z., Khan,I.A., "Steady-state Analysis of Parametric Frequency Changer", ibid, Vol. Mag-13, No.4, 1977,pp.1070-4.
8. Sen, P.K., Fam, W.Z., "Analysis of the Parametric Converter", ibid, Vol. IECI-26, No. 2, 1979, pp.93-98.
9. Fam, W.Z., Sen, P.K., "A State-model Representation of the Parametric Transformer", Electric Machines and Electromechanics, Vol. 4, No.3, 1979, pp.305-314.
10. Swift, J.W., "Power Transformer Core Behaviour Under Transient Conditions", IEEE Trans. Vol.PAS-90,1971,pp.2206-9.

APPENDIX

Design data of the experimental model (Fig.1):

$T = 2.7$ cm, $l = 14.7$ cm, $W = 9.4$ cm, $N_1 = N_2 = 180$ turns

Constant equivalent circuit parameters:

$R_1 = R_2 = 0.562$ ohm, $R_{m1} = R_{m2} = 750$ ohm,

$X_1 = X_2 = 0.21$ ohm at 50 Hz.