Establishing a Web Based Archive of Papers in Computational Electromagnetics

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Summary

- We extend the proposals and ideas put forward at the Compumag conference in Aachen (2007) and CEM conference in Brighton (2008).
- It is suggested that a Web based system could and should be developed to create a definite archive of publications in the area of Computational Electromagnetics.
- The need for such an archive has arisen as a result of a tendency of duplication in published work and to assist in the refereeing process.

Perceived needs

- We felt that the record of early work is in danger of being lost,
  - e.g. the Compumag Oxford (1976) [4] and Grenoble (1979) [5] which were published by the organising bodies. The same also applies to CEFC and to other EM conferences.
- The community needs to create a mapping of innovative work onto the main areas of scientific development so that a better understanding of attribution and citation could be made.

Perceived Needs (2)

- A definitive bibliography of available books (in print or Web) should be established.
- The body of knowledge that is catalogued is in itself of historical significance but perhaps of greater importance is the identification of problem areas for the future.
  - Main reason for all this is to limit the duplication that is appearing in the literature and to assist the refereeing processes for both academic journals and conferences.

A WEB Based System

- It is suggested that the existing Web based archival system be greatly extended and enhanced.
  - A facsimile copy of the first two Compumag conferences (Oxford 1976 and Grenoble 1979) has alreay been posted on the Compumag Society Web site [7].
- Also available on the Web site are facsimiles of the technical articles published in the ICS Newsletter [8]. Initially these articles were shorter and reported on recent advances in a particular area – they were in fact more like learned society journal papers, although invited rather than submitted – but gradually they evolved into more substantial reviews, often of ten pages or more.

Archive framework

- A central component of the archive should be a list of papers that have shaped the modern developments of CEM
  - It is essential that the members of this list are accepted by the community and monitored by a small working party. The Chair should be appointed by the ISC board.
- To establish a coherent mapping we need to define a criterion for inclusion.
  - No paper is completely new but it must not merely duplicate earlier work and must contain at least one innovative step. A significant step forward is valid, however, if it improves the efficiency and applicability of an existing method or indeed adapts a technique previously applied to a different discipline, say from a branch of mathematics.

Historical examples

- The example given in [3] of Richardson (1910) [9], who rigorously established the five point finite difference formula and applied it to real engineering problems.
  - Whilst Richardson was drawing partially on the work of Runge (1908) and Boltzmann (1892) he qualifies as a significant innovator as he established the rules of the method and perhaps ushered in the modern age of Numerical Methods.

Evolution of FD

Ludwig Boltzmann (1844 -1906)

1892

In München 1892/93 Ludwig Boltzmann gave a course on the mechanical potential, which after the tragic death of Boltzmann was reported by his student, the astronomer Hugo Buchholz.

$$4f_0 = f_1 + f_2 + f_3 + f_4$$

1908 Carl David Tolmé Runge (1856 – 1927)

Applied the 'unit square' formula (above) to simple problems without proof

1910 Lewis Fry Richardson (1881-1953)

First systematic attack with proofs and real applications, showing,in general, how to replace PDE's with algebraic equations

1918 Heinrich Liebmann (1874-1939)

Heinrich Liebmann considers Boltzmann´s treatment of the Dirichlet principle as a highlight, seeing here a "new proof" for the principle . He further extended the technique.

Relaxation methods – R.V. Southwell 1935-1946

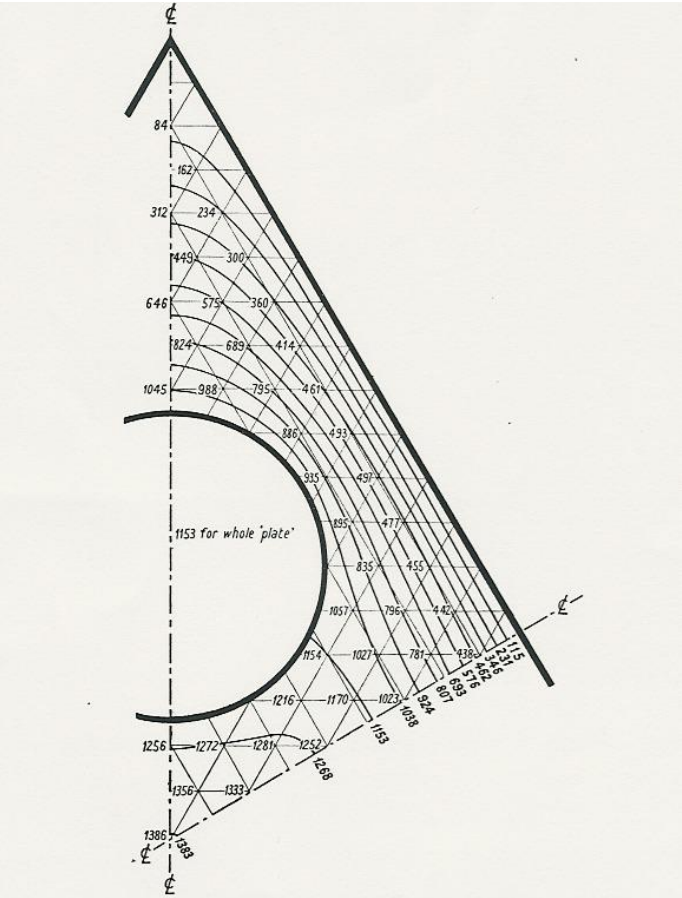


Fig. 23. The torsion problem solved for a pierced triangular shaft. (O. C. Zienkiewicz)

Torsion Problem OC Zienkiewicz

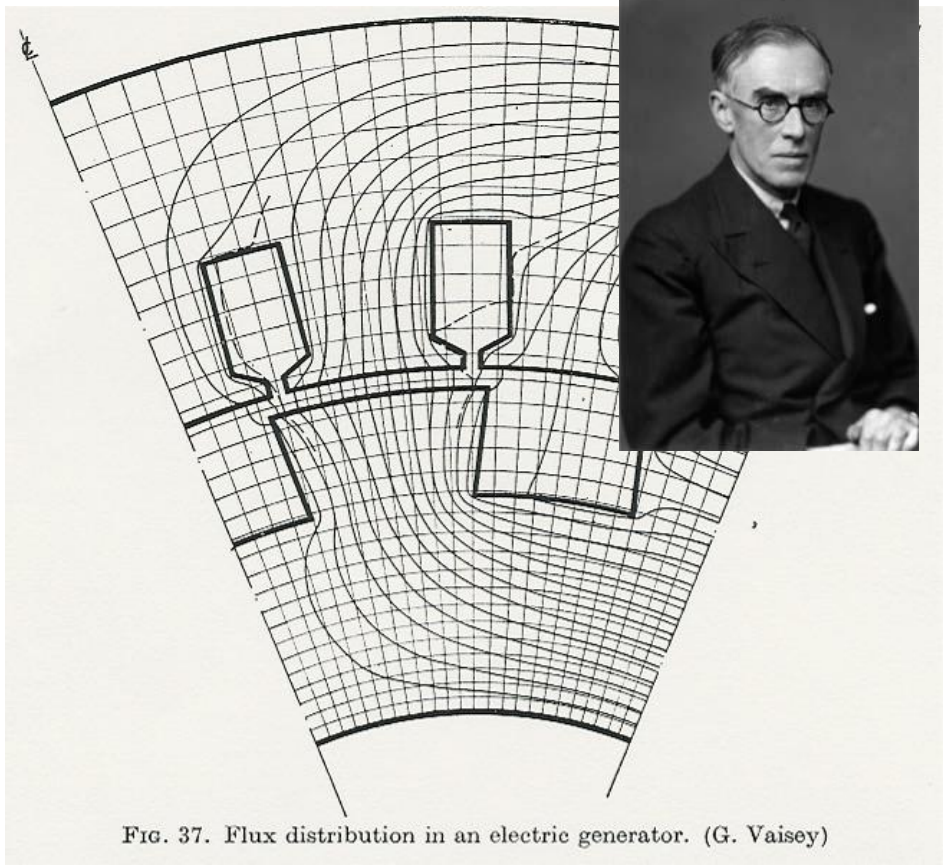


Fig. 37. Flux distribution in an electric generator. (G. Vaisey)

Motor Problem – problem solved in conformal mapping on to plane x-y space by G Vaisey

Suggested key papers in FD

- Highly developed discipline of mathematics
  - 18-19 C. Gauss (1823), Mohr (1868), Runge (1908)
  - 1950-1980 Widely used for CEM for LF problems
    - E.g. Trutt (1962) [1], Erdelyi (1966) [2], Viviani & Molinari (1978) [3], Muller & Wolff (1976) [4], Stoll[7]
  - Powerful and universally used for HF problems
    - E.g. Yee (1966), Weiland (1977)

[1] F.C. Trutt. *Analysis of Homopolar Inductor Alternators*, PhD thesis, University of Delaware, 1962

[2] E.A. Erdelyi and S.V. Ahmed, "Non-linear theory of synchronous machines on load", *IEEE Trans. on PAS*, 85, p. 792, 1966

[3] G. Molinari et al, "Finite difference method with irregular grid and transformed discretisation metric", *IEEE PES Winter Mtg.*, 1978

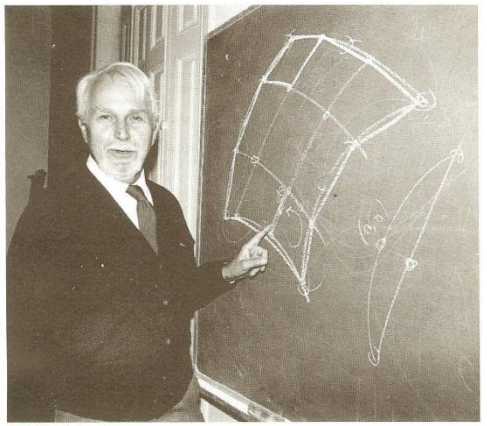
[4] W. Muller and W. Wolff, "General numerical solution of the magnetostatic equations", *Tech. Rep. 49(3)*, AEG Telfunken, 1976

[5] K.S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media", *IEEE Trans. On Antennas and Propagation*, AP-14, pp. 302-307, 1966

[6] T. Weiland, 'A discretisation method for the solution of Maxwell's equations for six component fields', *Electron. Commun. (AEU).*31, 116, 1977.

[7] R.L. Stoll, The Analysis of Eddy Currents, Clarendon Press, 1974.

Key Papers in FEM


O. C. Zienkiewicz, at class.

- A late arrival driven by the needs of industry
  - Origins in mechanics Courant (1943)[1] but based on work of Rayleigh (1870), Ritz (1909) Galerkin(1915)[2]
  - Method named and made systematic by Turner, Clough et al in 1956[3]
    - other early pioneers include Argyris(1964), Tonti (1969), Zienkiewicz(1967)[4], Irons, Finlayson(1972)
  - Mathematical basis established (1967)
    - Oden (1969)[5], Strang & Fix (1973), Babuska (1983)

[1] R Courant, “Variational Methods for the solution of problems of equilibrium and vibrartions”, Bull.Amer.Math. Soc. 49, 1-23, 1943

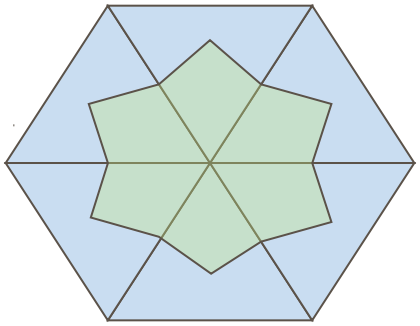
[2] B.G. Galerkin, “Series Solution of some problems of elastic equilibrium of rods and plates”, *Vestn. Inyh. Tech*, 19, 987, 1915

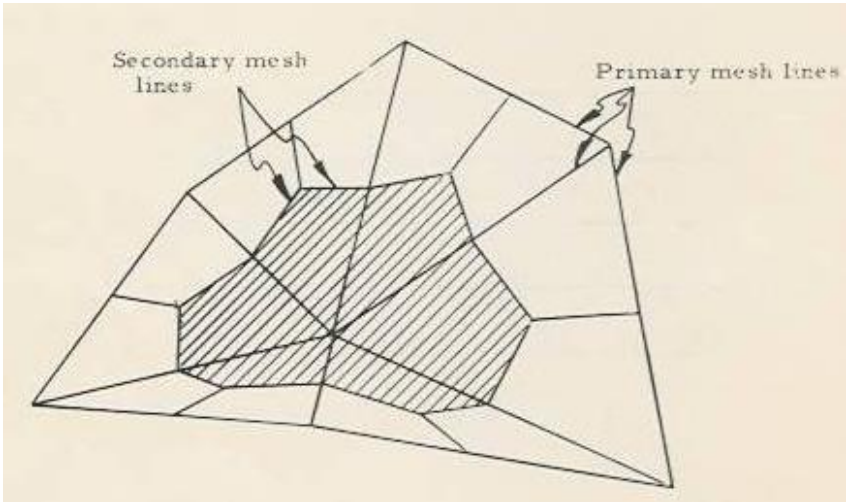
[3] M.J. Turner et al, “Stiffness and deflection analysis of complex structures”, *J Aero Sci*, vol 23, p.805, 1956

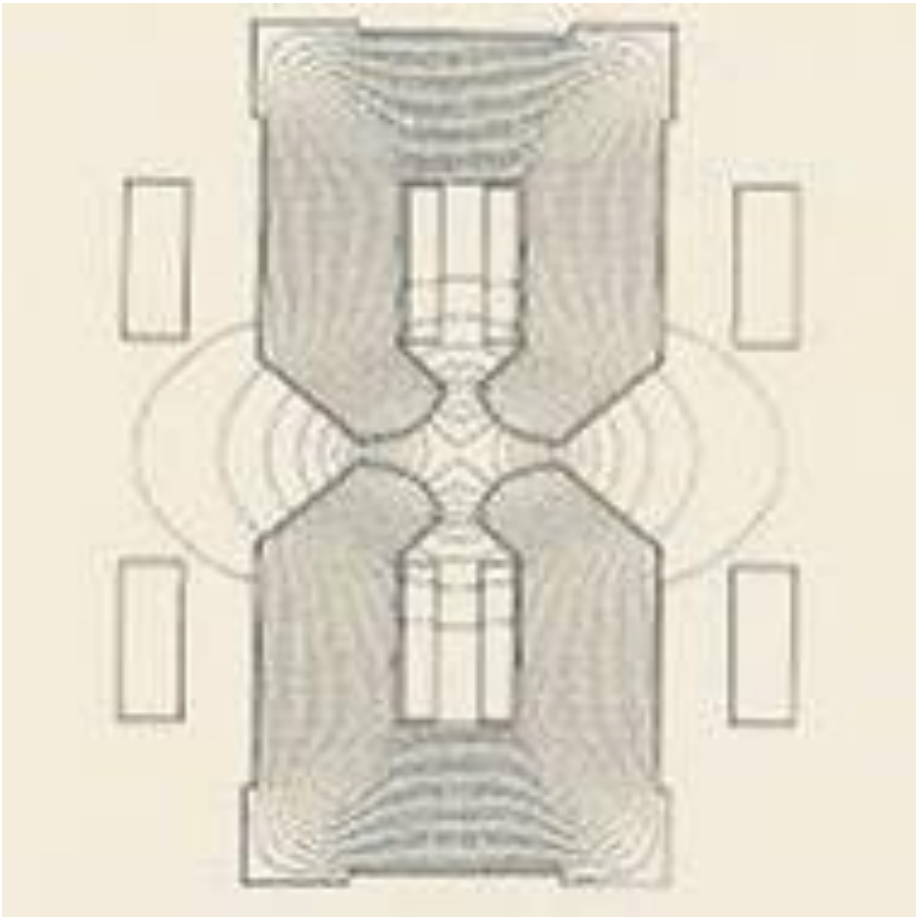
[4] O. C. Zienkiewicz, and R Taylor, The Finite Element Method, McGraw Hill, 1967

[5] J.T. Oden, “A general theory of finite elements”, Int. J. Num Meth. Eng, 1, 1969

Trim Code - Alan Winslow et al 1964







Winslow in 1962 demonstrated the equivalence of FD, FE & resister analogue for solving the Poisson Equation discretised by an irregular triangular mesh

Electrical Engineering FE Pioneers

Peter Silvester & MVK Chari

Analysis of Turbo-Alternator Magnetic Fields by Finite Elements, IEEE Trans, PAS-90, 1971

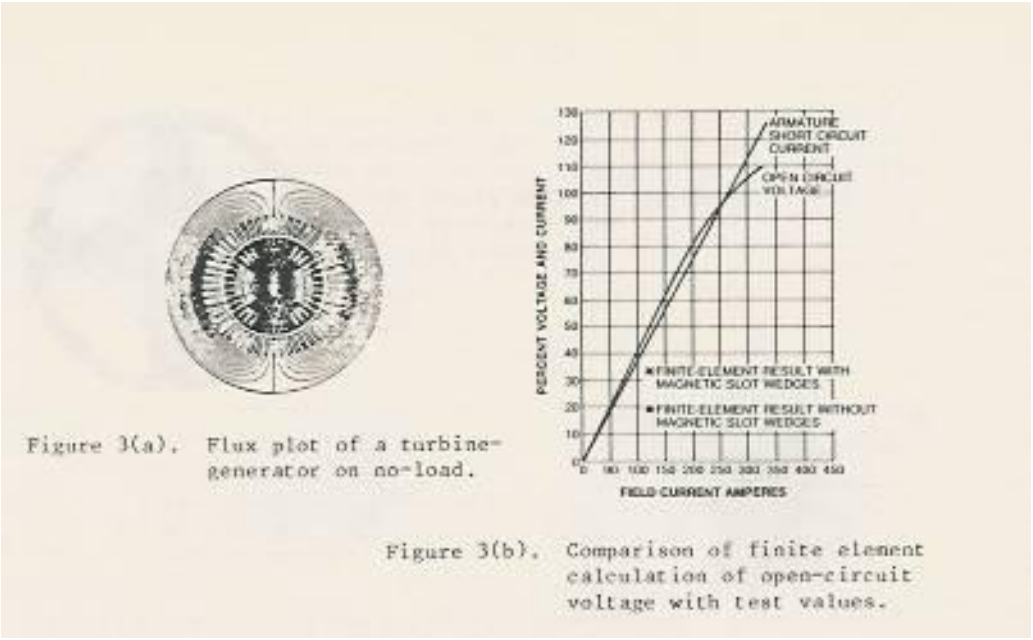


Figure 3(a). Flux plot of a turbine-generator on no-load.

Figure 3(b). Comparison of finite element calculation of open-circuit voltage with test values.

- Silvester et al introduced and generic higher order elements.
  - The polynomials using simplex coordinates allowed a formulation to be accomplished once and for all for a prototypal triangle [1].
- From this time the method became widespread leading to generalised applications for time dependent and 3D problems [2,3,4,5]

[1] P.P. Silvester, “High-order polynomial triangular finite elements for potential problems,” *Int. J. Engineering Science*, 7, 849-861, 1969.

[2] C.J. Carpenter, “Comparison of alternative formulations of 3-D magnetic field and eddy current problems at power frequencies,” *Proc. IEE,* vol 124, no 11, 1977.

[3] J.L Coulomb, A. Konrad, J.C. Sabonnadiere, and P Silvester, “Finite element analysis of steady state effect in a slot-embedded conductor,” *IEEE WPM A76-189-1*, 1976.

[4] J. Simkin, and C.W. Trowbridge, “On the Use of the Total Scalar Potential in the Numerical Solution of Field Problems in Electromagnetics,” *IJNME*, vol. 14, p.432, 1978.

[5]T. Nakata, and N. Takahashi, “Direct Finite Element Analysis of Flux and Current Distributions under Specified Conditions,” *IEEE Trans. Magn.*, vol.18, 1982.

Integral Methods (IM)

- IM, unlike DF use integral equation forms.
  - Also known as Moment Methods and were described theoretically by Harrington in 1968 [1].
  - Work of Halacsy based on a point dipole [2]
    - he gathered together many early workers at a series of small conferences held at Reno, Nevada, (1968-1973).
  - This approach generalised to include 3D modelling and non linear materials by the Rutherford Laboratory group[3]

[1] R.F. Harrington, *Field Computation by Moment Methods*, Macmillan, New York, 1968.
[2] A.A. Halacsy, *Proc. 2nd Reno Conf. on Analysis of Magnetic Fields*, Nevada, p. 56, 1969.
[3] M.J. Newman, C.W. Trowbridge, and L.R. Turner, "GFUN:An Interactive Program as an Aid to Magnet Design," *Proc. 4th Int. Conf. Magnet Technology*, Brookhaven, 1972.

Boundary Element Method

- Another class of integral procedures is the so called Boundary Element Method [1,2, 3] based on applications of Greens integral theorems. Whilst these methods are often difficult to apply they can produce accurate economic solutions and have been used extensively in both static and time dependent problems.

[1] M. A. Jaswon, “Integral Equation methods in potential theory,” *Proc. Roy. Soc*., A, p.23, 1963.
[2] J. Simkin, and C.W. Trowbridge, “Magnetostatic Fields Computed using an Integral Equation derived from Green’s Theorem,” in *Compumag Conference on the Computation of Magnetic Fields*, 1976.
[3} I Mayergoyz, “ Boundary Integral Equations of Minimum Order for the calculation of Three-Dimensional Eddy Current problems”, *IEEE Trans. Magn*. ,vol. 18, no. 2, 1982

Whitney (Edge) Elements

- Physical conditions are satisfied with respect to continuity. Introduced to CEM by Bossavit [1] though the ideas stem from Whitney in 1957 [2]
  - Rediscovered by the FE community under the category of 'mixed elements' by Nedelec (1980) [3]. Subsequent work by Bossavit and Verite [4] , Mur and de Hoop [5] , Biro, Preis & Richter [6] and Tsiboukis et al demonstrated the effectiveness for CEM problems generally.

[1] A. Bossavit and J.C. Verite, 'A mixed FEM-BIEM method to solve 3-D eddy current problem', *IEEE Magn Trans*, (18), pp. 431-435, 1982

[2] A. Bossavit, "Whitney forms: a class of finite elements for three-dimensional computations in electromagnetism", *IEE Proc. A*, vol 135, pp. 493-500, 1988.

[3] H. Whitney, *Geometric integration theory*, Princetown University press, 1957

[4] J. C. Nedelec, "Mixed Finite Elements in R3", *Numerische Mathematic*, 35, Springer-Verlag, pp. 316-341, 1980

[5] G. Mur and A. de Hoop, "A Finite Element method for computing 3d EM Fields in Inhomogeneous Media", *IEEE Mag Trans*, Vol 21, 1985

[6] O Biro, K Preis, K Richter, "On the use of the Magnetic Vector Potential in the Nodal and Edge Finite Element Analysis of 3D Magnetostatic problems", *IEEE Magn. Trans*., vol. 32, no. 3, 1996

[7] T. Yioultsis, and T. Tsiboukis, "Multiparametric Finite Elements: a Systematic Approach to the construction of 3-D, Higher Order, Tangential Vector Shape Functions," *IEEE Trans. Magn*., vol. 32, no. 3, 1996.

Vital Importance of Optimisation

- Optimisation plays a key role in the design of any device and can include:
  - Interactive graphics and visualization of electromagnetic fields
  - Knowledge based techniques applied to electromagnetic design and analysis
  - Expert systems for design
  - Multi-Objective Problems

D.A Lowther, “Accelerating the computer-based simulation and design of electromagnetic devices by applying knowledge”, IEEE Trans. On Magnetics, Vol 38, Issue 2, Mar 2002

J.K Sykulski, “Computational electromagnetics for design optimisation: the state of the art and conjectures for the future”, BULLETIN OF THE POLISH ACADEMY OF SCIENCES TECHNICAL SCIENCES, Vol. 57, No. 2, 2009

Possible scenario

- The scenario put forward in reference [3] is one way forward:
  - Define subject areas, e.g. Fundamentals and Theory, Differential Methods, Integral Methods, Hybrid and Semi-analytical, Numerical Techniques, Software Methodology, Material Modelling, Mesh Generation and Adaption, Post-Processing, Coupled Problems, Optimization and CAD.
  - Compile a list of candidate papers utilizing input from the community. A short summary of each selected paper should be included as well as a critical justification of its importance.
  - The archive working party to make the selection; this already has started within the remit of the International Compumag Society but we suggest representatives from other organizations should also be involved.

Possible Scenario (2)

- Establish a file of review papers perhaps drawing on the existing review articles that have been published in the ICS Newsletter [8] and commissioning new ones to cover gaps.
- The community, in its widest sense, should be invited to criticize the selection, suggest modifications and ideas for extending its relevance and value. We also recommend that time should be made available to the working party at each Compumag conference for discussion with the community.

Book Bibliography

- Book bibliography
  - A list of published books and monographs with reviews attached should also be added to the archive and include not only those that are regularly cited by researchers but also those which relate CEM to broader areas.
  - As argued before [1], CEM is both a special case and part of the wider subject of computational mechanics, with its own very rich literature and significant achievements. Similarly, field simulation aided design draws on advances in general optimization techniques, coupled formulations, developments in other branches of physics, and so on – care should be taken when establishing a list of relevant books but the potential value of such a catalogue should not be underestimated.

ICS Newsletter

- A common feature of the most recent publications in the Newsletter is that they describe the state of the art, emphasise the important milestones, describe the most recent advances and provide a rich list of references; it could therefore be argued that they are indeed true reviews.
- Therefore the archive will benefit not only from the list of historic papers which will aim to correctly attribute the classic contributions to our subject but read in combination with the Newsletter Reviews give a deeper understanding of our subject. It is important therefore that gaps in our coverage should be identified and new review commissioned.

Some recent examples

- Remarks on optimal design methods in electromagnetic *by Paolo Di Barba*
- State of the Art in the Simulation of Electromagnetic Fields based on Large Scale Finite Element Eigenanalysis *by Wolfgang Ackermann, Galina Benderskaya and Thomas Weiland*
- Phenomenological modeling of magnetic hysteresis *by Ermanno Cardelli, Edward Della Torre and Antonio Faba*
- The Boundary Element Method in Full-wave Electromagnetics *by J. Guy Morgan*
- Overview of Meshless Methods *by Simonea Viana*
- Electromagnetic energy and multiphysics modelling *by François Henrotte*
- Network models of three-dimensional electromagnetic fields *by Andrzej Demenko and Jan K. Sykulski*
- Modelling of high temperature superconductors and their practical applications *by Ryszard Palka*
- Reformulation and Generalisation of the Air-Gap Element *by Herbert De Gersem and Thomas Weiland*
- Handbook for the computation of electromagnetic forces in a continuous medium *by François Henrotte*

Feedback from the Community

- Before completing the first edition of the archive a mechanism must be created for the community to contribute to the process and provide constructive criticism.
- This may result in some items removed and others to be added as it is important that some consensus is reached at this stage. It would probably be unrealistic to hope for complete agreement, but general support should be possible.

Maintenance

- System maintenance and updates
  - Once the initial set of papers and books has been established, the archive must be maintained but also allowed to grow to reflect progress and new achievements

The role of the International Compumag Society

- It seems natural and almost obvious that the Society should take a leading role in this venture. If successful, this will offer an important service to the community.

Considerations for Future

- At the Brighton conference [3] the authors said that, ‘over the next few months the authors together with the proposed ICS working party will develop a case study to demonstrate how the creation of the archive could be achieved following a preferred scenario – this should not be viewed as a definite proposal but more as an example using a selected narrow research topic’.

Working Group

- Although for a variety of reasons the working party has not been constituted yet, the authors hope to have wide ranging discussions during the Sydney conference. Also at that time it is hoped that a working party will be established.

Conclusion

- To conclude and re-emphasize the points made earlier, feedback from researchers will be an essential factor in establishing an archive system to which the community would subscribe. The CEM Community should accept this as a challenge to create appropriate mechanisms, establish a process and provide reliable feedback mechanism.

References

1. C. W. Trowbridge and J. K. Sykulski, "Some Key Developments in CEM and their Attribution," *IEEE Transactions on Magnetics*, vol. 42, no. 4, pp. 903-906, 2006.
2. C. W. Trowbridge and J. K. Sykulski, "Towards Establishing a Definitive Archive of CEM Papers," *16th Conference on the Computation of Electromagnetic Fields COMPUMAG*, 25 – 28 June 2007, Aachen, Germany, pp. 7-8.
3. C. W. Trowbridge and J. K. Sykulski, "Establishing an Archive of Papers on Computational Electromagnetics," *IET 7th International Conference on Computation in Electromagnetics CEM 2008*, 7 – 10 April 2008, Old Ship Hotel, Brighton, UK, pp. 64-65.
4. J. Simkin and C.W. Trowbridge (Eds), *Proc. Compumag Conference Oxford*, Rutherford Laboratory, 1976.
5. J. C. Sabonnadiere (Ed), *Proc. Compumag Conference Grenoble*, Labotatoire d'Electrotechnique, 1978.
6. J. Brauer (Ed), *Proc. Fifth Annual Magnetics Computation Meeting (Formerly the GFUN users meeting)*, Milwaukee, USA, October 27/28, 1983.
7. ICS Web Site, http://www.compumag.co.org
8. *International Compumag Society Newsletter*, ISSN 1026-0854
9. L. F. Richardson, "The approximate arithmetical solution by finite differences of physical problems …", *Phil. Trans. Royal Society*, 210A, pp. 307-357, (1910).