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BOEING

February 3, 1997
G-1151-SJA-97-061

Document Control Desk
United States Nuclear Regulatory Commission
Washington, D.C. 20555

Reference: a) Boeing Letter G-1151-RSO-92-365 dated August 31, 1992; R. S. Orr to the NRC Operations Center

b) NRC Letter Docket No. 99901227 dated August 12, 1992; L. J. Norrholm to R. S. Orr; Subject: Response to 10 CFR 21 Inquiry

Dear Sir or Madam:

In accordance with the reference correspondence and 10 CFR 21, Boeing is sending the NRC the attached error notice(s) received from our former software suppliers. Because of unknown current addresses, the following former customers were not notified:

Reactor Controls, Inc.

Echo Energy Consultants, Inc.

Nuclear Applications and Systems Analysis Company (Japan)

Nuclear Power Services

Error notices have been sent to our other former customers.

Very truly yours,

S. Charles, for

Sandra J. Andrews
Nuclear Administrator
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e-mail: Sandra.Andrews@PSS.Boeing.com

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IE19

Enclosure(s): Reissue of ANSYS letter dated January 8;
ANSYS QA Notice QA96-09R1

ANSYS

ANSYS, Inc.
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Telephone 412.746.3304
Facsimile 412.746.9494

January 27, 1997

Attn: Class3 Error Recipients

Attached you will find a cover letter which references the Class3 Error Reports you recently received accompanied by a letter dated January 8, 1997. There was an error in this letter that I wanted to clarify. The original letter stated that you should have received 96-45 R1 in 1996. However, 96-45 R1 was not issued in 1996. It is just being finalized now and will be issued shortly.

Also attached to this letter is QA Notice QA96-09 R1. It was decided to get this report out to the customers quickly instead of waiting for our next quarterly mailing. The enclosed letter has been updated to include this report also.

Please discard the letter dated January 8 and place the attached one in its place. Sorry for any confusion this may have caused.

Sincerely,

ANSYS, Inc.

Bonny Podolek

Bonny Podolek
Quality Assurance

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January 23, 1997

Dear Class3 Error Recipient:

Enclosed you will find ANSYS Class3 Error Reports 96-47, 96-48, 96-49, 96-50, 96-51, 96-52, 96-53 and QA Notice QA96-09 R1. This QA Notice has been issued to further clarify the warning given in QA96-09 of potential inaccuracy in results using the three dimensional magnetic vector potential formulation in problems with permeable materials.

In the year 1996 the following Class3 Error Reports were issued: Class3 Error Reports 96-01 through 96-53, 96-02 R1, 95-55 R1, 95-49 R1, 95-39 R1, 95-37 R1, 94-68 R2, 93-33 R1, 93-03 R1, and 92-25 R1. ANSYS QA Notices QA96-01 through QA96-09 and QA96-05 R1 were also issued. ANSYS Support Coordinator Bulletin SCB 96-01 was also issued. If you are missing any of these reports, please contact Bonny Podolek at 412-873-2858 and they will be provided to you.

I would like to remind you of the various ways that you can receive Class3 error information. Quarterly, Class3 errors will be delivered by mail to the ANSYS Support Coordinator listed on your ANSYS license agreement. Please complete and return the attached change form if there has been a change in personnel or an address change so that these reports can be delivered promptly.

For users desiring access to Class3 errors on a more timely basis you can be added to our email distribution list. To register for email notification of reports, simply send an email request including your email address, company name/address and ANSYS agreement number to bpodolek@ansys.com. If you are a subscriber to email distribution, please keep us informed of any changes in your email address by emailing bpodolek@ansys.com.

Finally, Class3 Errors and QA Notices are posted on ANSYS's Internet HomePage. The address is http://www.ansys.com. They are located in the ANSYS Zones section of the HomePage under Customer. The username to enter this area is "customer" and the password is "ain1fm" (ANSYS is number 1 for me).

For your convenience, also enclosed with this mailing you will find ANSYS Class3 Error Summary Report Summaries sorted both by error number and keyword for Rev. 5.2 and Release 5.3

I would like to take this opportunity to extend to you wishes for a prosperous new year.

Sincerely,

ANSYS, Inc.

William J. Bryan
Quality Assurance Manager

ANSYS QA NOTICE

NOTICE NO: QA96-09 R1

SUBJECT: *ELEM62* *ELEM97* *MAGNETICS*

QA Notice 96-09 was issued on October 22, 1996 warning users of potential inaccuracy in results using the three-dimensional magnetic vector potential (MVP) formulation in problems with permeable materials (i.e., air and iron regions) ANSYS Inc, is actively working to resolve the accuracy issue. The intent of this notice is to update you on our progress.

<u>Background</u>

At Revision 4.4A, ANSYS introduced a state-of-the-art nodal-based 3-D MVP formulation [1] in the SOLID96 element to address general three-dimensional electromagnetic field problems with an emphasis on time-varying field analysis. This formulation complemented our scalar potential formulations which are primarily focused at solving magnetostatic problems. The MVP formulation was later implemented in the SOLID62 and SOLID97 elements.

This formulation uses a standard nodal-based degree of freedom set containing three vector potentials in non-conducting regions and an additional scalar potential in conducting regions. In addition, it uses a Coulomb gauge condition on the vector potential to ensure uniqueness. As formulated, the vector potential is assumed to be continuous in the entire solution domain, even across material boundaries. ANSYS Inc. has benchmarked the formulation against many problems published in the literature with excellent success. Most of these problems are eddy current problems with analytical solutions or experimental comparisons. In addition, we compared three-dimensional solutions to two-dimensional planar and axisymmetric solutions for general static, harmonic, and transient test cases and obtained excellent agreement.

Reports of solution inaccuracy using the nodal-based MVP formulation has recently appeared [2] in the literature for the case of problems containing multiple materials (i.e. problems with air and iron). Results from this and other references suggested only a minor inaccuracy with the nodal-based MVP formulation. There has been no report in the literature, to the best of our knowledge, of any major accuracy issues with the MVP formulation. It has been suggested in the literature that a solution to the inaccuracy problem can be found by allowing the normal component of the vector potential to jump across the air-iron interface.

It was brought to the attention of ANSYS Inc. in the spring of 1996 that there may be a more severe limitation in the solution accuracy of the nodal-based MVP formulation with air-iron interfaces than had been reported in the literature. In particular, the ANSYS Verification Manual Problem VM190 was solved using the MVP formulation and compared results to the General Scalar Potential (GSP) formulation originally used in the problem (see attachment). The calculated mmf drop in the iron domain was severely under predicted by the MVP formulation. In addition, the magnetic field in the iron domain appeared to be extremely low in comparison to the GSP formulation. This solution inaccuracy was more severe than reported for other problems in the literature, perhaps tied to the fact that in this problem the

iron appears as a multiply-connected domain (i.e., the mmf drop is totally contained in the iron domain).

Prompted by a question regarding solution accuracy in the 3-D MVP formulation, we immediately undertook an extensive study of the formulation. We first confirmed that the problem VM190 indeed gave inaccurate results using the MVP formulation as was reported by the customer. We extensively reviewed our implementation of the MVP formulation and have concluded that there is no error in the coding of the formulation.

It has been proposed that our gauging method may be a source of the error. We have tested the Coulumb gauge against an ungauged formulation and have found little difference in the solution results. Hence we are convinced that gauging is not the major source of solution inaccuracy.

Our next step was to study the effect of allowing the normal component of the vector potential to jump across air-iron interfaces. This had been reported in the literature to improve solution results [2]. We accomplished this by taking the standard ANSYS Rev 5.3 product and run test cases where each element of a model was individually created with independent node sets, then tied together with constraint equations that allowed for continuity of the tangential component of the vector potential across element edges, and a discontinuous normal component of the vector potential. This in essence creates what can be called a nodal-based edge implementation of the MVP formulation. For the test cases examined, we did indeed obtain excellent solutions. With the standard nodal-based formulation, we observed again poor results. Our observations lend credence to the fact that improved results are obtained by allowing the normal component of the vector potential to jump across air-iron interfaces. This also helped to confirm that our nodal-based implementation is correct and that the inaccuracy has to do with the continuity of the potential across air-iron interfaces.

We investigated the possibility of enhancing SOLID97 and SOLID62 with a nodal-based edge implementation by allowing for a discontinuous normal component of the MVP through the use of internally generated constraint equations. This approach however would lead to large computational inefficiencies not acceptable in a commercial environment.

Our next approach was to consider a direct edge element formulation. Edge elements have appeared in the literature over the last several years as an alternative method. Degrees of freedom are related to the edge of an element rather than the nodes of an element. A sample paper considering an edge element implementation can be found in [3]. Most of the work in edge elements has been directed at resolving spurious modes in high frequency applications, not at resolving solution inaccuracies in low frequency applications. However, the edge formulation circumvents the MVP problem by solving for edge potentials directed along the element edge, hence there is no component of a potential normal to air-iron interfaces to be concerned with. In January of 1997 we successfully implemented an edge formulation for static analysis that appears to be very robust and accurate for air-iron problems.

Our Plan

ANSYS Inc. is committed to developing an accurate 3-D formulation applicable to static, harmonic, and transient analyses. We plan a commercial release of a new edge element formulation in the 5.4 release of ANSYS. We are presently testing the new edge element

formulation for magnetostatic problems and developing it for eddy current problems. At the time of this writing we are not yet able to commit the eddy current implementation for the 5.4 release, but will make every attempt to do so.

The edge element formulation will be far more efficient than the nodal-based counterpart by using far fewer degrees of freedom (one degree of freedom at each element edge rather than 3 degrees of freedom at each node). In addition, we are implementing a Tree gauging technique that will further reduce the active degree of freedom set. This and other developments lead to the following advantages for our implementation;

- The edge formulation will be more accurate and efficient than the nodal-based MVP formulation
- We have implemented the edge element into a brick form which will help to minimize the model size and degrees of freedom. To the best of our knowledge, there are no other commercial codes with brick edge elements.
- Our new brick element is much more immune to the effects of element distortion and thus will provide accurate results for highly distorted meshes.
- Our ICCG iterative solver is not experiencing convergence difficulties with our edge element implementation that has been reported in the literature.
- The new formulation constitutes a consistent link between static and dynamic analyses, thus shortening the learning curve and minimizing user error.
- The method does not require several solution passes as may be required when using the scalar potential formulations in SOLID96.
- The method can treat any arbitrary source current distribution irrespective of the solution geometry and material characteristics.

Our long-term strategy will be to implement the edge element into wedge and tetrahedral shapes and extend to a higher-order edge implementation.

In summary, ANSYS Inc. has had early success in developing a fully robust 3-D formulation for static and dynamic analysis of electromagnetic fields. Preliminary results on magnetostatic tests indicate that the new formulation will accurately solve problems containing multiple materials of differing permeability. Our attention now is focused on eddy current analysis to model dynamic effects. We recommend the use of the scalar potential formulations in SOLID96, SOLID98, and SOLID5 for general 3-D magnetostatic problems, and in the limiting case of problems containing non-permeable materials, the use of SOLID97 with the MVP formulation for harmonic and transient problems.

Benchmark Results

To illustrate our progress, we have taken the Verification Manual problem VM190 originally solved using our Generalized Scalar Potential Formulation (in SOLID98) and re-solved the problem using our nodal-based MVP formulation and our new edge-element formulation. Table 1 compares the solution accuracy for the three methods in terms of the mmf drop calculated in the iron with the command macro MMF. An identical hexahedral mesh was used for all three runs.

Table 1 MMF Calculation in Iron Region

GSP Formulation	198 Amp-turns
Edge Formulation	204 Amp-turns
MVP Formulation	1.66 Amp-turns

Table 2 compares problem size and solution statistics for the three approaches. The Frontal Solver was used since the wavefront was relatively small. Note the significant reduction in the active degrees of freedom for the Edge formulation over the MVP formulation, resulting in a wavefront similar to that of the GSP formulation.

Table 2 Solution Statistics

Method	Active dof's	RMS Wavefront	Solution Time (sec)
GSP Formulation	8866	241	264
Edge Formulation	18888	246	257
MVP Formulation	28404	633	866

References

1. Biro, O. and Preis, K. "On the Use of the Magnetic Vector Potential in the Finite Element Analysis of Three-Dimensional Eddy Currents", IEEE Trans Magn. Vol 25, No. 4, pp 3145-3159, July 1989.
2. Biro, O., Preis, K., and Richter, K., "On the Use of the Magnetic Vector Potential in the Nodal and Edge Finite Element Analysis of 3D Magnetostatic Problems", IEEE, Trans Magn. Vol 32, No. 3, pp. 651-654, May 1996.
3. Kameari, A., "Calculation of transient 3D eddy current using edge elements", IEEE Trans. Mag., Vol 26, pp. 466-469, March 1990.

AFFECTED VERSIONS: Revision 4.4A through Release 5.3

COMMENTS:

For general static magnetic field analysis, use the scalar potential formulations offered in elements SOLID5, SOLID96, and SOLID98.

AUTHOR: Dale F. Ostergaard **Date:** January 22, 1997

REVIEWED BY QA: William J. Bryan **Date:** January 22, 1997

APPROVAL: John A. Swanson **Date:** January 22, 1997